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The Development of Methods for Predicting Soil Moisture Content - Miles City, Montana

MILES CITY EXTENSION OF THE VICKSBURG INFILTRATION PROJECT

THE DEVELOPMENT OF METHODS FOR PREDICTING SOIL MOISTURE CONTENT

REPORT ON THE MILES CITY, MONTANA STUDY

By

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Conducted for

WATERWAYS EXPERIMENT STATION

CORPS OF ENGINEERS, U.S. ARMY

Vicksburg, Mississippi

Intermountain Forest and Range Experiment Station

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THE DEVELOPMENT OF METHODS FOR PREDICTING SOIL MOISTURE CONTENT

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THE DEVELOPMENT OF METHODS FOR PREDICTING SOIL MOISTURE CONTENT

Report on the Miles City, Montana Study

by

Austin E. Helmers and Raymond J. Boyd [1]

INTRODUCTION

The Forest Service, U. S. Department of Agriculture, at the request of the Waterways Experiment Station, U. S. Army Corps of Engineers, made preliminary investigations for developing soil moisture prediction methods in 1951 at Vicksburg, Mississippi. Expansion to other areas began in 1952. One of the areas chosen was the U. S. Range Livestock Experiment Station near Miles City, Montana. The Miles City study areas were fenced and the soil moisture instruments installed in November 1952. The installations were completed and field measurements begun in April 1954. Field observations were discontinued in August of the same year. The results of the Miles City study are reported herein.

1/ Foresters, Intermountain Forest and Range Experiment Station, Inland Empire Research Center, Spokane, Washington. Howard W. Lull, of the Vicksburg Infiltration Project, Vicksburg, Mississippi, was in charge of the technical aspects of the study until September, 1954. The study was completed under the technical supervision of Jerry S. Horton who succeeded Lull as project leader. C. A. Wellner, Leader, Inland Empire Research Center was in administrative charge of the project. James C. Holland, Soil Scientist, assisted with field installations in November 1952, made certain special field measurements in 1954, and assisted with compilation of data. Walter R. Houston and Raymond Baker, both with the Agricultural Research Service, Miles City, Montana, conducted the regularly scheduled field observations.

Factors affecting soil moisture were discussed in three previous reports (3, 8, 9)[2/] on the Vicksburg studies. The field and analytical procedures for the Miles City study were prescribed by the above three Vicksburg reports and later modifications.

DESCRIPTION OF EXPERIMENTAL AREAS

Location

The study sites were within the area operated by the U. S. Range Livestock Experiment Station (Agricultural Research Service, U. S. Department of Agriculture), about 2 miles west of Miles City, Custer County, Montana. Site designations and locations are shown in table 1.

2/ Numbers in parentheses refer to literature cited, page 60.

Table 1.--Description of experimental areas.

Descriptive designation	Location	Waterways Experiment Station Classification: Site No.	Waterways Experiment Station Classification: Trafficability soil-climate classification
River	SW¼ Sec. 8, T7N, R47E, MPM		3Ca
Highway	NW¼ Sec. 24, T7N, R46E, MPM		3Cb
Gumbo	NE¼ Sec. 12, T7N, R46E, MPM		3Cb

Geology and Physiography 3/

The area in the vicinity of Miles City lies within the Great Plains Physiographic Province. The area is rough broken land with local tracts of shale ridges and buttes and gently rolling land bordering the stream valley alluvium. In places the shale has weathered to a gently rolling land but more commonly the slopes are undergoing active erosion producing a sharply rolling surface and some buttes with very steep faces. The Highway and Gumbo sites were located on the broad, smooth, gently sloping alluvial material separating the rough broken land from the first bottom on which the River site was located. The elevation of the experimental areas is about 2400 feet.

3/ From Gieseker (4)

Soils 4/

The Miles City area lies in the general region of Chestnut soils. The study sites were all on valley alluvium of two series:

(1) Havre silt loam, a medium-textured soil (River and Highway sites.)

(2) Bowdoin clay, a heavy-textured soil (Gumbo site.)

Both the Havre, Bowdoin, and several closely related series are extensive along most of the Montana river valleys east of the mountains. Limited areas have been covered by detailed surveys. Havre soils are extensively used for irrigation farming for such crops as alfalfa, sugar beets, beans and potatoes. Bowdoin clay and related soils are the heaviest and most difficult to manage in the area. Most of them are in native range except where drainage is good and salt is no problem.

The soils of both the Highway and Gumbo sites probably consist in part of colluvial-alluvial sediments originating from the shale areas above.

River and Highway Sites

Both the River and Highway sites were located on Havre silt loam. Soils of the Havre series are young and have acquired only a small quantity of organic matter. The Bureau of Plant Industry, Soils, and Agricultural Engineering, Division of Soil Survey, described the Havre series as follows:

4/ Soil descriptions were assembled from Gieseker (4), DeYoung (1) and mimeographed data from the Division of Soil Survey, Bureau of Plant Industry, Soils, and Agricultural Engineering.

HAVRE SERIES

The Havre series includes moderately dark to rather light-colored alluvial soils along the larger or the permanently flowing streams in the Chestnut and Brown soils zones. The underlying alluvium is light colored, limy, and friable. These soils differ from those of the Banks series in having a more coherent subsoil; from Harlem soils in having lighter-colored surface layers and more porous upper subsoil layers which afford better internal drainage; from Huff soils in having less sandy subsoils; and from Cass soils in having much lighter-colored surface soils and limy, less sandy, and more coherent subsoils. Drainage is better in the Havre than in Laurel soils.

I. Soil Profile(Havre loam):

		Range in thickness
1.	0-8" Grayish-brown (10YR 4/2 dry) to dark grayish-brown (10YR 3/2 moist), massive to soft cloddy loam; commonly calcareous in lower part.	4-10"
2.	8-40" Grayish-brown (moist) to light grayish-brown (dry) friable, massive loam, silt loam, or very fine sandy loam; calcareous; commonly coherent though less so below than above a depth of about 20 inches.	30-60"

II. Range in Characteristics: These soils vary in the thickness of the surface layers, which are calcareous throughout in places. The subsoils have no definite structure but commonly have vertical breakage or form. In some localities they contain enough sand or sand and gravel to become semi-coherent or incoherent in the lower part, usually below 2 feet. Thin layers of clay are not uncommon in the subsoil and substratum.

III. Topography: Nearly level.

IV. Drainage: Surface drainage is slow or lacking, but the internal drainage is good. Water table usually is several feet below the surface.

V. Vegetation: Short and tall-grass associations; buck brush; cottonwood trees are along the streams in places.

VI. Use: Under irrigation these soils produce high yields of alfalfa, small grains, sugar beets and Irish potatoes. Corn and small grains yield fairly well under dry-farming methods except in the drier years.

VII. Distribution: Montana, North Dakota, South Dakota, Nebraska, Wyoming, and possibly Colorado.

Type location: Valley County, Montana.

Series established: Milk River Area, Montana, 1928.

1/ Provisional Soil Survey color names, based on Munsell color charts.

TDR-MB
6-1-39
Rev. FAH
2-3-40
Rev. FAH 6-8-40
Rev. FAH 9-20-40
Rev. JT 5-2-46

Division of Soil Survey
Bureau of Plant Industry, Soils,
and Agricultural Engineering
Agricultural Research Administration
U. S. Department of Agriculture

Gumbo Site

The Gumbo site is on Bowdoin clay described as follows by the Division of Soil Survey, BPISAE:

BOWDOIN SERIES

The Bowdoin series includes heavy-textured Alluvial soils developing on clayey alluvium of flood plains in the Chestnut and Brown soils zones. The parent materials were derived mainly from areas of Cretaceous clays and clay shales. These soils may be distinguished from Harlem soils, with which they are sometimes associated, by their lighter-colored surface layers heavier-textured subsoils and higher content of salts. Their position on flood plains distinguishes them from Orman soils of the terraces and from McKenzie soils which occur in undrained basins.

I. Soil Profile(Bowdoin Clay):

		Range in thickness
1. 0-6"	Olive-gray 1/ (5.0Y 5/1 dry) to very dark olive-gray (5.0Y 3/1 moist) massive clay; cracks widely on drying; usually noncalcareous; neutral.	5-8"
2. 6-18"	Light olive-gray (5.0Y 6/1 dry) to dark olive-gray (5.0Y 4/2 moist) massive or indistinctly prismatic clay; breaks into hard clods when dry; usually calcareous; neutral to slightly alkaline.	10-14"
3. 18"	Light olive-gray (5.0Y 6/1 dry) to olive-gray (5.0Y 5/1 moist) massive clay splotched with white salt accumulations and dark-brown iron stains; calcareous; neutral to slightly alkaline.	

II. Range in Characteristics: In places the clay is more than 4 feet thick. Areas where drainage is unusually poor may have a high content of soluble salts. In some areas the clay is underlain by very fine sandy loam below a 30-inch depth.

III. Topography: Nearly level.

IV. Drainage: Both surface and internal drainage are slow. The soils are subject to overflow.

V. Vegetation: Bluejoint grass is dominant. Greasewood and saltgrass grow on the more alkaline and saline areas.

VI. Use: Alfalfa and sweet clover are grown on the better-drained tracts. Large areas of salty land have little value except for hay production or for pastures.

VII. Distribution: The northern part of Montana and western parts of North Dakota and South Dakota.

Type location: Milk River Area, Montana.

Series established: Milk River Area, Montana, 1928.

1/ Provisional Soil Survey color names, based on Munsell Color Charts.

TDR:MB
12/13/39
Rev. FAH
4/20/41
Rev. WMJ
5/23/46

Division of Soil Survey
Bureau of Plant Industry, Soils, and Agricultural Engineering
Agricultural Research Administration
U. S. Department of Agriculture

Soil Texture, Plasticity, and Bulk Density

The soils laboratory of the Waterways Experiment Station made the mechanical analyses of soil texture and determined the Atterberg plasticity constants for the surface foot of soil from each of the three sites. Bulk density was determined with a San Dimas sampler (9, Vol. 2, p. A31). These physical characteristics are summarized in table 2.

Soil Moisture Tension

Soil moisture content at a tension of 60 cm of water (.06 atmosphere) (table 3) were obtained at Vicksburg by use of a tension table.

Vegetation

Vegetation, through the process of transpiration, is probably the factor having the most pronounced effect on soil moisture depletion. A number of meteorological factors undoubtedly exert an influence, but the greatest factor is their modification by vegetation. Vegetation develops in response to environment and as it develops, it in turn reacts on the environmental factors. For purposes of this report, the effects of natural vegetation are considered as relatively stable from year to year because the overall changes in factors influencing it are rather slight over long periods of time.

Table 2.--Soil texture, plasticity, and bulk density

Site and soil type	Layer or Horizon	Depth	Mechanical analysis 1/ U.S.D.A.				Engineering classification	Plasticity constants 2/			Bulk density
			Gravel	Sand	Silt	Clay		Liquid limit	Plastic limit	Plasticity index	
		Inches	Percent					Percent			gms/cc
River		0-3	0	14	51	35		45	22	23	1.27
		3-6	0	12	57	31		46	21	25	1.40
		6-9	0	16	49	35		46	23	23	1.36
		9-12	0	12	53	35		48	21	27	1.36
Highway		0-3	0	16	58	26		35	21	14	1.29
		3-6	0	17	56	27		32	19	13	1.35
		6-9	0	20	59	21		30	20	10	1.33
		9-12	0	14	65	21		31	21	10	1.35
Gumbo		0-3	0	13	52	35		48	22	26	1.21
		3-6	0	10	52	38		52	22	30	1.28
		6-9	0	10	52	38		51	20	31	1.36
		9-12	0	11	47	42		53	20	33	1.49

1/ Particle size classification:

Gravel	2.0 mm
Sand	2.0 - 0.05 mm
Silt	0.05 - 0.002 mm
Clay	0.002 mm

2/ Atterberg Limits

Table 3.--Soil moisture tension

Site	Soil series	Depth	Soil moisture content at moisture tensions (atmospheres) of: 0 1/	.06
		Inches	Percent	
River	Havre silt loam	0-3	29.4	26.6
		3-6	29.1	26.5
		6-9	30.6	26.0
		9-12	32.4	28.0
Highway	Havre silt loam	0-3	32.3	27.0
		3-6	34.4	28.9
		6-9	37.0	30.7
		9-12	35.4	29.3
Gumbo	Bowdoin clay	0-3	32.3	29.6
		3-6	36.6	34.3
		6-9	31.4	29.3
		9-12	36.8	32.6

1/ Saturation

As far as can be determined, the Miles City plots are located on native range land and have never been under cultivation. The areas are all part of experimental pastures and were grazed until November 1952 when the soil moisture units were installed and the experimental plots were fenced. Cured growth from the 1953 season was removed by hand pulling and clipping in April of 1954 when the study was reactivated. Ground cover on the study sites was then equivalent to that of the grazed area outside of the enclosures.

The River site is covered to a density of approximately 4/10 with a mixture of bluestem wheatgrass (Agropyron smithii), annual sweet clover (Melilotus alba), and annual weeds. Bluestem wheatgrass is predominant, making up 70 percent of the total composition. Twenty percent of the plant cover is annual sweet clover and 10 percent annual weeds. Judging from the 1953 growth, this plot has the most luxuriant vegetation both in height and density (fig. 1).

The Highway site supports a cover of 2/10 density, predominantly sand dropseed (Sporobolus cryptandrus). This species constitutes 70 percent of the total cover. Annual grasses, weeds, and perennial forbs account for 25 percent of the forage, and needleandthread grass (Stipa comata) 5 percent (fig. 2).

Figure 1. River site on April 6, 1954. Soil moisture and strength plots have been clipped of 1953 growth. Vegetation is predominantly bluestem wheatgrass (Agropyron smithii).

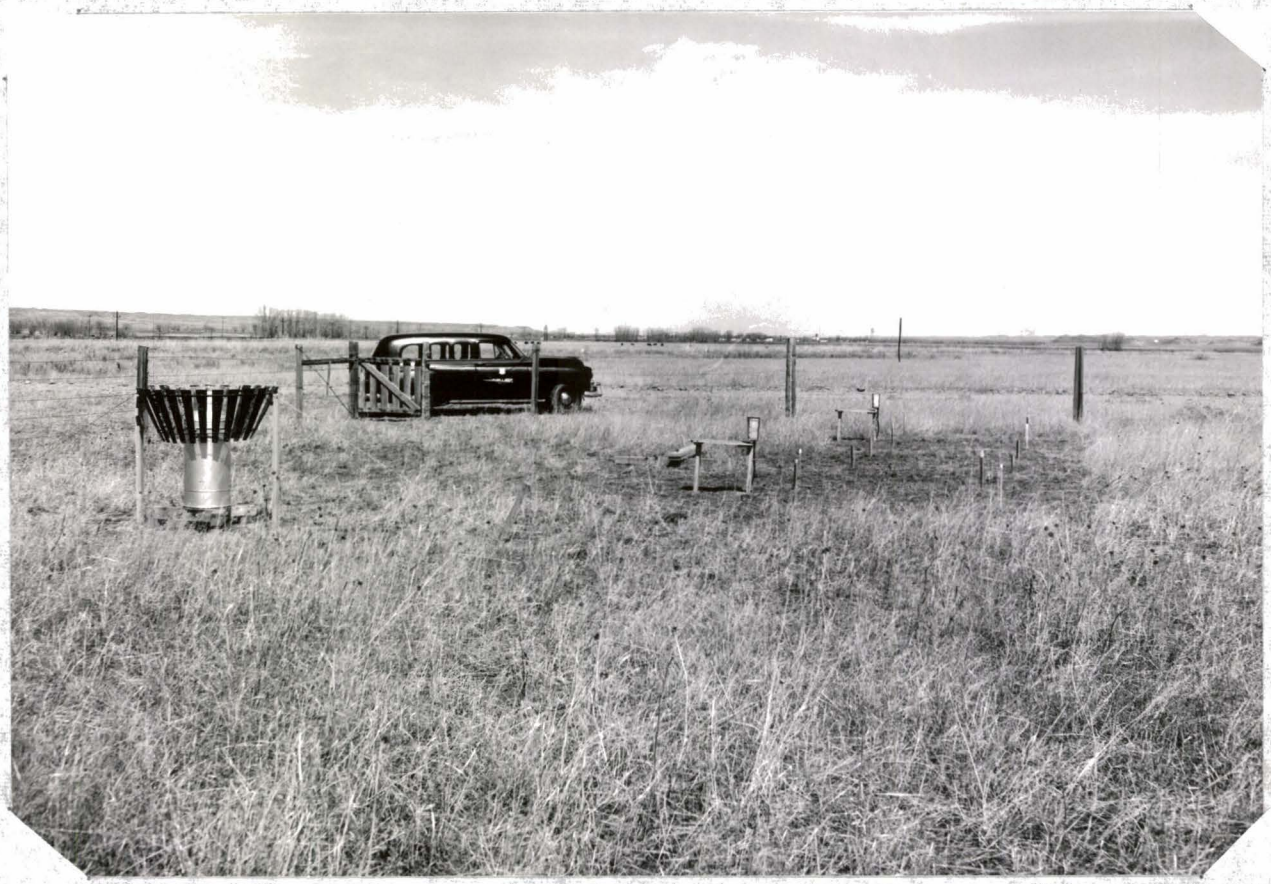

Figure 2. Highway site on April 6, 1954. Growth from 1953 has just been removed from soil moisture and strength testing plots. Sand dropseed (Sporobolus cryptandrus) is the dominant plant.

Sparse vegetation cover is typical of the heavy clay soil upon which the Gumbo plot is located (fig. 3). Here the density is less than 1/10. The dominant vegetation is annual weeds (80 percent) which put on fast growth in May and June while moisture is available, but die in early summer when the weather becomes dry and hot. The small amount of perennial grasses (such as Agropyron smithii) and forbs (20 percent) indicate that this site would not fully utilize late summer and fall rains.

According to Holscher and Woolfolk (5), plant growth generally commences in late March or early April. Observations by residents indicate that the 1954 season was 2 to 3 weeks later than usual. About 70 percent of the annual precipitation falls during the April to September period. Vegetation makes its most rapid growth in May and June, the months of greatest precipitation. Then, depending on species, it either dies or goes into a dormant stage by late June to late July. Late summer and early fall rains and suitable temperatures occasionally result in good fall regrowth of the dormant perennials. This was true of the 1954 season.

Application of artificial rainfall to the soil moisture study plots on June 22 and 23 probably came when most of the annual weeds and grasses had started to die and was ineffective in prolonging their life. The extra moisture undoubtedly delayed the curing of the perennial grasses, possibly to the extent that they were better able to take advantage of the mid-August rains.

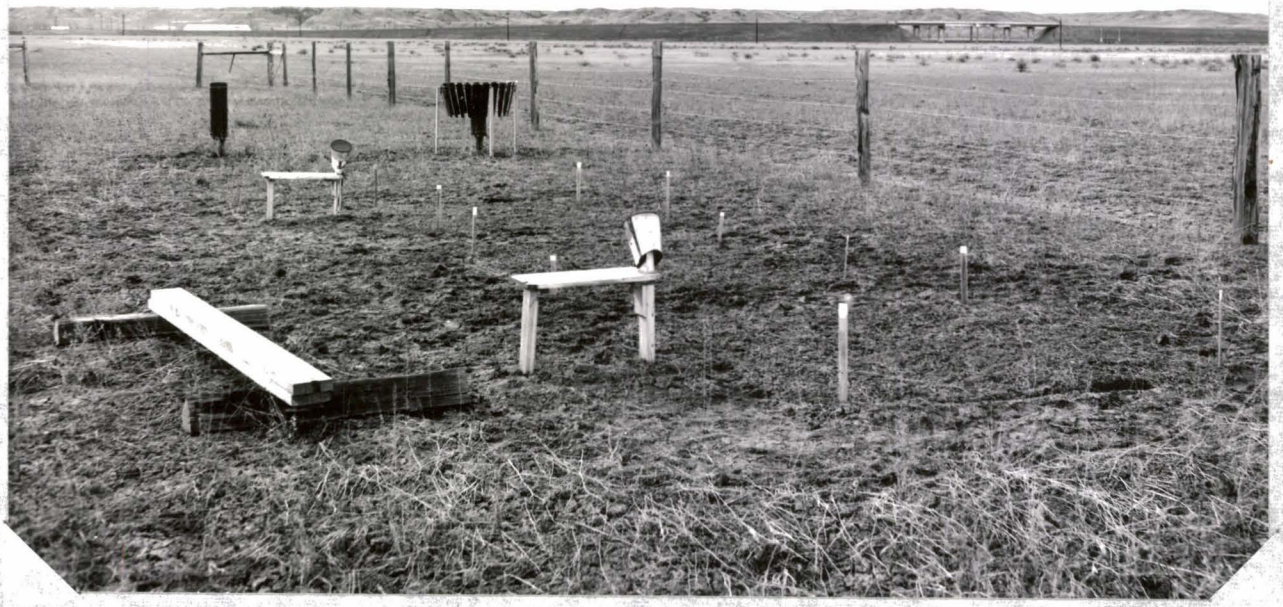

Figure 3. Sparse vegetation at Gumbo site is illustrated by the "ungrazed" portion of the plot with 1953 growth remaining. Annual weeds dominate the vegetation on this heavy soil. April 6, 1954.

METEOROLOGICAL FACTORS 5/

The climate at Miles City is of the mid-continental type. Precipitation is scanty because the principal moisture bearing air masses precipitate the greater part of their moisture in crossing the mountain ranges to the west. Winters are cold and subject to frequent sudden changes in temperature. Summers are hot with a dry atmosphere and a very high percentage of sunshine. Table 4 summarizes the temperature and precipitation data for Miles City.

The growing season averages 158 days, with a range of from 116 to 186 days. The average date of the last killing frost in the spring is April 30. The earliest date of the last frost is April 5 and the latest May 31. The first killing frosts in the fall have occurred as early as September 12 and as late as October 24. The average date of the first killing frost is October 5.

The mean annual temperature is 45.5° F. Absolute extremes in temperature are 111° F. in July and -49° F. in February (4). July is normally the warmest month and January the coldest.

5/ From (7) and "Climatogical Data, Montana Section" published by the U. S. Weather Bureau.

Table 4.--Climatic means at Miles City, Montana

Month	Mean monthly air temperature: 1/	Mean monthly precipitation: Miles City 1/ CAA-AP	Mean monthly precipitation: Experiment Station 2/	Total Snowfall 3/
	Degrees F	Inches	Inches	Inches
January	16.1	.47	.56	6.4
February	21.1	.36	.45	4.5
March	31.2	.70	.80	7.1
April	46.0	1.08	1.03	2.6
May	57.0	1.71	1.96	1.9
June	65.2	2.84	2.72	0
July	75.0	1.41	1.50	0
August	72.3	1.10	1.10	0
September	60.4	1.20	1.01	0.1
October	48.3	.94	.87	1.2
November	32.8	.49	.49	3.9
December	20.7	.51	.49	5.6
Annual	45.5	12.31	13.00	33.3

1/ Monthly Climatogical Data, Montana Section, U.S. Weather Bureau.

2/ U.S. Range Livestock Experiment Station, Fort Keogh. Record from 1878 to 1953, incl.

3/ Reference (4).

Annual precipitation averages 12.81 inches at the CAA-Airport Station and 13.00 inches (76-year mean) at the U. S. Range Livestock Experiment Station about 2 miles west of Miles City. Only 5.51 inches of precipitation was received in 1934, the driest season. Precipitation during 1879, the wettest season of record was 22.79 inches (4). June is normally the wettest (2.72 inches) month and November, December, and January the driest with less than 0.50 inch of precipitation at the Experiment Station.

Winds are generally westerly and northwesterly and rather strong during late winter and early spring. Warm (foehn) winds occur in the winter season. The hot winds of the summer season sometimes cause soil blowing and crop damage.

Basic meteorological factors, such as solar radiation, precipitation, wind, air temperature, and relative humidity, affect soil climate and moisture directly through such processes as heat exchange, evaporation, infiltrating water, changes in soil air, and exchange of soil and atmospheric air. These factors also indirectly affect the soil through their effects on vegetation. From the standpoint of predicting soil moisture depletion at a particular site, vegetation is the principal means through which meteorological factors exert an influence on soil moisture losses. In comparison, the direct effects of meteorological factors independent of vegetation are small. On bare areas, of course, the physical factors may have the major effect. Meteorological factors are variable from day to day but their net change is usually small from year to year. Thus the differences in net effects of meteorological factors on vegetation between one year and the next usually are not pronounced.

Rainfall adds directly to the water in the soil and is the most important meteorological factor in predicting soil moisture accretion. Several other meteorological factors may result in soil moisture gains but their effectiveness as compared to rainfall is minor.

Instrumentation

U. S. Weather Bureau standard precipitation gates were installed at the River and Gumbo sites (figs. 1 and 3, respectively) and a weighing-recording gage was used at the Highway site (fig. 2). All three gages were equipped with Alter-type wind shields. The unshielded U. S. Weather Bureau standard gage at the Gumbo site (fig. 3) was not part of this study. Artificial rainfall applications using a Rocky Mountain infiltrometer (2) were used in late June and early July to augment natural rainfall as a means of accumulating soil moisture accretion data.

Air temperature and wind data from the Miles City weather station were assumed representative of the study sites.

Precipitation

Normal April-August, inclusive, precipitation is 8.14 inches at Miles City and 8.31 inches at the Experiment Station (table 4). Precipitation in the same period in 1954 was 7.19 inches, 86 percent of normal, at the Experiment Station (table 5). April-July, inclusive, rainfall was deficient, from 40 percent of normal in May to 88 percent in June, but excessive, 222 percent of normal, in August.

Daily precipitation is shown in tables 6-14, inclusive.

Table 5.--Monthly precipitation

Month	Site				
				Experiment Station	
	River	Highway	Gumbo	Current	Departure from normal
	Inches				
April	.70	.59	.60	.88	-.15
May	.66	.62	.94	.78	-1.18
June	2.43	2.14	2.04	2.40	-.32
July	.85	.95	.57	.69	-.81
August	2.93	2.59	2.06	2.44	1.34

Table 6.--Meteorological and soil factors, River site,

April and May, 1954.

RI – INT
Infiltration Project

HYDROMETEOROLOGICAL FACTORS

SITE RIVER

DATE	SOIL MOISTURE TIER 1 Soil Depth (Inches)						TIER 2 Soil Depth (Inches)						SITE MEANS		SOIL TEMPERATURE TIER 1 Soil Depth (Inches)				TIER 2 Soil Depth (Inches)				PRECIPITATION[1]		AIR TEMPERATURE				RELATIVE HUMIDITY	WIND VELOCITY	TIME
1954	0-3	3-6	0-6	6-9	9-12	6-12	0-3	3-6	0-6	6-9	9-12	6-12	0-6	6-12	1-1/2	4-1/2	7-1/2	10-1/2	1-1/2	4-1/2	7-1/2	10-1/2	TIER 1	TIER 2	MAXIMUM	MINIMUM	MEAN	DEG. DAYS			
April	(Inches)														(Degrees F)								(Inches)		(Degrees F)				(%)	(mph)	(Hours)
6	1.03	.94	1.97	.96	.98	1.94	.98	.92	1.90	.92	.88	1.80	1.94	1.87	49	46	43	42	49	47	40	42									1645
7	1.00	.94	1.94	.96	.99	1.95	.96	.93	1.89	.93	.90	1.83	1.92	1.89	42	40	41	41	40	40	37	42									1025
12	.82	.93	1.75	.96	.98	1.94	.87	.91	1.78	.92	.92	1.84	1.77	1.89	59	46	43	42	54	48	40	43									1115
14	.75	.91	1.66	.96	.98	1.94	.82	.90	1.72	.92	.92	1.84	1.69	1.89	54	52	51	50	54	52	48	50									0905
15	.71	.89	1.60	.95	.98	1.93	.80	.88	1.68	.93	.92	1.85	1.64	1.89	46	47	48	48	46	47	45	50	.12	.12							0855
16	.68	.88	1.56	.94	.97	1.91	.78	.88	1.66	.92	.91	1.83	1.61	1.87																	
18	.64	.87	1.51	.92	.97	1.89	.74	.86	1.60	.90	.90	1.80	1.56	1.85	46	46	47	47	46	45	43	48	.14	.14							0900
19	.73	.86	1.59	.92	.96	1.88	.74	.86	1.60	.90	.90	1.80	1.60	1.84									T	T							
21	.67	.84	1.51	.91	.95	1.86	.71	.84	1.55	.89	.90	1.79	1.53	1.83	40	39	42	43	39	39	38	43	T	T							0815
23	.63	.80	1.43	.90	.94	1.84	.68	.80	1.48	.88	.88	1.76	1.46	1.80	50	48	48	47	49	48	44	49									0830
26	.49	.74	1.23	.87	.92	1.79	.58	.74	1.32	.83	.86	1.69	1.28	1.64	50	50	50	50	50	50	47	51									0825
28	.46	.72	1.18	.85	.91	1.76	.56	.71	1.27	.78	.85	1.63	1.23	1.70	40	44	47	48	43	46	46	50	.39	.39							0845
29	.56	.71	1.27	.82	.90	1.72	.56	.71	1.27	.77	.83	1.60	1.27	1.66	38	41	43	45	38	40	39	46	.05	.05							0820
30	.58	.64	1.22	.82	.88	1.70		.71		.66	.81	1.47		1.59																	
Mean	.70	.83	1.53	.91	.95	1.86	.77	.83	1.59	.87	.88	1.75	1.53	1.80				45.7				46.7									
																					Total		.70	.70							
May																															
3	.52	.71	1.23	.81	.81	1.62	.60	.70	1.30	.76	.80	1.56	1.27	1.59	33	36	39	41	34	36	36	42	T	T							0835
5	.59	.71	1.30	.79	.81	1.60	.59	.70	1.29	.75	.72	1.47	1.30	1.53	42	42	42	42	42	42	40	45									0810
7	.68	.70	1.38	.77	.80	1.57	.57	.70	1.27	.71	.76	1.47	1.32	1.53	50	48	49	49	50	49	46	51	.10	.10							0820
10	.52	.68	1.20	.73	.82	1.55	.54	.68	1.22	.67	.72	1.39	1.21	1.47	54	54	54	54	54	54	52	55									0825
12	.47	.66	1.13	.70	.78	1.48	.52	.66	1.18	.64	.70	1.34	1.16	1.41	59	58	58	56	59	59	54	59									0815
14	.42	.62	1.04	.68	.76	1.44	.49	.63	1.12	.59	.69	1.28	1.08	1.36	63	62	62	60	63	63	59	64									0812
17	.38	.56	.94	.64	.74	1.38	.46	.59	1.05	.54	.67	1.21	1.00	1.29	59	59	59	59	59	59	55	60									0820
19	.36	.53	.89	.60	.71	1.31	.44	.55	.99	.50	.65	1.15	.94	1.23	69	63	62	60	66	64	59	64									0935
21	.30	.50	.80	.55	.67	1.22	.38	.50	.88	.48	.62	1.10	.84	1.16	70	69	69	67	70	69	66	69	.01	.01							0820
23	.47	.49	.96	.54	.66	1.20	.37	.50	.87	.48	.60	1.08	.92	1.14	59	58	59	59	59	59	55	62	.24	.24							0955
24	.48	.49	.97	.54	.64	1.18	.38	.50	.88	.48	.60	1.08	.93	1.13	55	54	57	59	54	54	54	59	T	T							0825
27	.48	.48	.96	.51	.62	1.13	.40	.47	.87	.48	.57	1.05	.92	1.09	56	56	58	59	56	55	54	60	.16[2]	.16[2]							0810
28	.48	.48	.96	.52	.62	1.14	.40	.48	.88	.48	.56	1.04	.92	1.09	56	56	56	56	56	56	54	58	.15	.15							1350
Mean	.47	.59	1.06	.64	.73	1.37	.47	.59	1.06	.58	.67	1.25	1.06	1.30				55.5				57.5									
																					Total		.66	.66							

[1] a=artificial precipitation
2/ 5/25/54.

Table 7.--Meteorological and soil factors, River site,

June, 1954.

RI– INT
Infiltration Project

HYDROMETEOROLOGICAL FACTORS

SITE RIVER

DATE	SOIL MOISTURE TIER 1 Soil Depth (Inches)						TIER 2 Soil Depth (Inches)						SITE MEANS		SOIL TEMPERATURE TIER 1 Soil Depth (Inches)				TIER 2 Soil Depth (Inches)				PRECIPITATION[1]		AIR TEMPERATURE				RELATIVE HUMIDITY	WIND VELOCITY	TIME
1954	0-3	3-6	0-6	6-9	9-12	6-12	0-3	3-6	0-6	6-9	9-12	6-12	0-6	6-12	1-1/2	4-1/2	7-1/2	10-1/2	1-1/2	4-1/2	7-1/2	10-1/2	TIER 1	TIER 2	MAXIMUM	MINIMUM	MEAN	DEG. DAYS			
	(Inches)														(Degrees F)								(Inches)		(Degrees F)				(%)	(mph)	(Hours)
June																															
1	.46	.48	.94	.49	.60	1.09	.41	.46	.87	.48	.56	1.04	.91	1.06	62	61	62	61	63	63	59	63									0820
2	1.02	1.00	2.02	.62	.60	1.22	1.26	.94	2.20	.48	.56	1.04	2.11	1.13	58	52	54	56	50	52	51	58	1.20	1.20							0825
3	.99	.96	1.95	.89	.60	1.49	1.02	.93	1.95	.53	.56	1.09	1.95	1.29	52	50	53	54	51	49	48	54									0814
6	1.04	.89	1.93	.84	.64	1.48	.91	.88	1.79	.61	.56	1.17	1.86	1.38	63	59	59	55	63	61	56	61	.34	.34							1015
7	.94	.88	1.82	.84	.63	1.47	.86	.88	1.74	.60	.57	1.17	1.78	1.32	56	56	58	58	56	56	54	60									0820
9	.77	.78	1.55	.76	.64	1.40	.69	.81	1.50	.59	.57	1.16	1.53	1.28	61	59	60	59	61	60	57	63									0820
11	1.01	.89	1.90	.75	.64	1.39	.92	.88	1.80	.58	.58	1.16	1.85	1.28	60	59	60	60	59	59	56	62	.56	.56							0825
14	.74	.74	1.48	.69	.65	1.34	.84	.75	1.59	.56	.58	1.14	1.54	1.24	67	66	68	65	68	68	64	68									0815
15	.68	.70	1.38	.65	.64	1.29	.53	.69	1.22	.54	.58	1.12	1.30	1.20	82	77	69	66	82	80	69	69									1500
16	.59	.69	1.28	.64	.66	1.30	.53	.68	1.21	.54	.58	1.12	1.24	1.21	63	65	66	66	65	67	64	69									1010
18	.48	.66	1.14	.59	.64	1.23	.50	.66	1.16	.52	.59	1.11	1.15	1.17	60	60	62	63	61	61	60	64									0815
21	.38	.56	.94	.50	.59	1.09	.44	.56	1.00	.49	.58	1.07	.97	1.08	69	68	68	68	69	69	67	70									0815
22	.36	.55	.91	.49	.59	1.08	.43	.54	.97	.48	.58	1.06	.94	1.07	64	66	68	68	67	68	68	71									0650
23	1.53	.88	2.41	.56	.61	1.17	.93	.89	1.82	.49	.58	1.07	2.12	1.12	69	68	67	66	71	70	65	69	1.20[a]	1.20[a]							1055
24	1.47	1.05	2.52	.93	.62	1.55	1.28	1.04	2.32	.92	.58	1.50	2.42	1.52	64	66	67	67	67	68	65	69	.72[a]	1.03[a]							0635
26	1.57	1.20	2.77	1.20	1.38	2.58	1.46	1.26	2.72	1.08	1.34	2.42	2.74	2.50	64	66	68	68	65	66	64	69	.28[2/]	.28[2/]							0645
28	1.15	1.07	2.22	1.07	1.12	2.19	1.22	1.14	2.36	1.06	1.10	2.16	2.29	2.18	67	65	67	65	67	67	64	69									0830
29	1.19	1.09	2.28	1.14	1.17	2.31	1.14	1.09	2.23	1.06	1.08	2.14	2.26	2.22	60	62	64	64	62	63	61	67	.05	.05							0830
30	1.02	1.03	2.05	1.08	1.12	2.20	1.08	1.08	2.16	1.05	1.08	2.13	2.10	2.16	55	59	62	63	58	59	59	64									0630
Mean	.91	.85	1.76	.77	.75	1.52	.87	.85	1.72	.67	.69	1.36	1.74	1.44				62.7				65.2									
																					Total		4.35	4.71							

[1]a=artificial precipitation
2/ 6/25/54

Table 8.--Meteorological and soil factors, River site,

July and August, 1954.

RI- INT
Infiltration Project

HYDROMETEOROLOGICAL FACTORS

SITE RIVER

DATE	SOIL MOISTURE														SOIL TEMPERATURE								PRECIPITATION[1]		AIR TEMPERATURE				RELATIVE HUMIDITY	WIND VELOCITY	TIME
	TIER 1						TIER 2						SITE MEANS		TIER 1				TIER 2												
	Soil Depth (Inches)						Soil Depth (Inches)								Soil Depth (Inches)				Soil Depth (Inches)				TIER 1	TIER 2	MAXIMUM	MINIMUM	MEAN	DEG. DAYS			
1954	0-3	3-6	0-6	6-9	9-12	6-12	0-3	3-6	0-6	6-9	9-12	6-12	0-6	6-12	1-1/2	4-1/2	7-1/2	10-1/2	1-1/2	4-1/2	7-1/2	10-1/2									
July	(Inches)														(Degrees F)								(Inches)		(Degrees F)				(%)	(mph)	(Hours)
1	.88	.98	1.86	1.05	1.08	2.13	.95	1.02	1.97	1.04	1.03	2.07	1.92	2.10	61	63	64	64	62	63	61	66									0730
2	.79	.95	1.74	1.01	1.05	2.06	.86	.97	1.83	1.00	.99	1.99	1.78	2.02	64	64	65	64	64	65	62	68									0815
7	.45	.74	1.19	.64	.77	1.41	.52	.69	1.21	.90	.77	1.67	1.20	1.54	69	73	74	72	73	74	73	77									0515
9	.44	.58	1.02	.58	.72	1.30	.48	.66	1.14	.54	.69	1.33	1.08	1.32	76	73	73	72	77	76	72	77	.13	.13							0850
14	.34	.50	.84	.50	.64	1.14	.42	.52	.94	.50	.63	1.13	.89	1.14	76	74	74	74	76	77	79	79									0840
15	.38	.50	.88	.48	.64	1.12	.40	.51	.91	.50	.62	1.12	.90	1.12	74	74	74	73	76	76	73	79	.17	.17							0820
16	.43	.49	.92	.48	.63	1.11	.39	.50	.89	.50	.60	1.10	.90	1.10	74	76	76	74	77	79	74	80									0515
26	.35	.48	.83	.45	.58	1.03	.36	.43	.79	.48	.55	1.03	.81	1.03	77	74	74	74	77	77	73	79	.55[2]	.55[2]							0815
Mean	.51	.65	1.16	.65	.76	1.41	.55	.66	1.21	.70	.74	1.43	1.18	1.42				70.9				76.1									
																				Total			.85	.85							
Aug.																															
3	.28	.46	.74	.41	.50	.91	.30	.39	.69	.48	.51	.99	.72	.95	87	86	80	77	87	86	80	80									1910
4	.34	.46	.80	.41	.52	.93	.29	.39	.68	.48	.50	.98	.74	.96	72	73	74	74	74	74	73	78	.17	.17							0820
6	.98	.46	1.44	.44	.54	.98	.29	.39	.68	.48	.51	.99	1.06	.98	69	69	69	69	69	69	68	73	.48	.48							0820
9	.82	.46	1.28	.43	.54	.97	.34	.39	.73	.48	.51	.99	1.00	.98	69	69	69	69	70	70	69	73									0830
12	.68	.48	1.16	.40	.54	.94	.34	.40	.74	.48	.51	.99	.95	.96	71	72	73	72	72	73	70	76	.27	.27							0818
13	1.25	.49	1.74	.40	.54	.94	.34	.40	.74	.48	.50	.98	1.24	.96	70	71	73	72	72	72	70	76	.31	.31							0615
16	1.12	.48	1.60	.43	.55	.98	.41	.41	.82	.48	.51	.99	1.21	.98	69	69	69	69	69	69	68	73	.68	.68							0905
17	1.11	1.18	2.29	1.15	.94	2.09	1.52	1.03	2.55	.48	.52	1.00	2.42	1.54	64	65	68	68	64	65	64	69	.98	.98							0815
20	.68	.97	1.65	1.02	.98	2.00	.87	.92	1.79	.50	.53	1.03	1.72	1.52	82	73	69	68	80	77	68	71									1310
21	.60	.94	1.54	1.00	.98	1.98	.76	.87	1.63	.52	.53	1.05	1.58	1.52	71	69	69	69	71	70	67	71	.04	.04							0930
23	.50	.82	1.32	.93	.94	1.87	.58	.76	1.34	.54	.54	1.08	1.33	1.48	65	67	69	69	66	67	64	69									0830
30	.41	.62	1.03	.67	.75	1.42	.46	.59	1.05	.49	.56	1.05	1.04	1.24	69	69	69	69	69	69	68	71									
Mean	.73	.65	1.38	.64	.69	1.33	.54	.58	1.12	.49	.52	1.01	1.25	1.17				70.4				73.3									
																				Total			2.93	2.93							

[1] a = artificial precipitation
2/ 7/17/54

Table 9.--Meteorological and soil factors, Highway site,

April and May, 1954.

RI- INT
Infiltration Project

HYDROMETEOROLOGICAL FACTORS

SITE HIGHWAY

DATE	SOIL MOISTURE														SOIL TEMPERATURE								PRECIPITATION[1]		AIR TEMPERATURE				RELATIVE HUMIDITY	WIND VELOCITY	TIME
	TIER 1						TIER 2						SITE MEANS		TIER 1				TIER 2												
	Soil Depth (Inches)						Soil Depth (Inches)								Soil Depth (Inches)				Soil Depth (Inches)												
1954	0-3	3-6	0-6	6-9	9-12	6-12	0-3	3-6	0-6	6-9	9-12	6-12	0-6	6-12	1-1/2	4-1/2	7-1/2	10-1/2	1-1/2	4-1/2	7-1/2	10-1/2	TIER 1	TIER 2	MAXIMUM	MINIMUM	MEAN	DEG. DAYS			
April	(Inches)														(Degrees F)								(Inches)		(Degrees F)				(%)	(mph)	(Hours)
6	.82	.76	1.58	.64	.58	1.22	.78	.80	1.58	.72	.58	1.30	1.58	1.26	47	43	43	42	46	42	42	39									1215
7	.80	.76	1.56	.64	.58	1.22	.76	.80	1.56	.72	.60	1.32	1.56	1.27	44	40	41	42	46	38	38	36									1120
12	.71	.74	1.45	.65	.58	1.23	.63	.75	1.38	.68	.60	1.28	1.42	1.26	64	47	43	42	69	49	43	39									1150
14	.67	.72	1.39	.65	.58	1.23	.58	.70	1.28	.64	.60	1.24	1.34	1.25	54	52	50	50	59	52	50	48									1030
15	.66	.71	1.37	.64	.57	1.21	.56	.68	1.24	.63	.59	1.22	1.30	1.22	46	46	46	48	45	43	46	45	.04	.04							0925
16	.63	.70	1.33	.64	.57	1.21	.55	.66	1.21	.62	.58	1.20	1.27	1.21																	
18	.79	.72	1.51	.64	.57	1.21	.74	.66	1.40	.59	.59	1.18	1.46	1.20	46	43	44	46	46	43	43	42	.24	.24							0925
19	.74	.72	1.46	.64	.57	1.21	.66	.66	1.32	.59	.58	1.17	1.39	1.19																	
21	.67	.71	1.38	.63	.57	1.20	.60	.65	1.25	.60	.58	1.18	1.32	1.19	40	38	41	42	41	36	38	38									0855
23	.61	.70	1.31	.63	.56	1.19	.56	.62	1.18	.58	.57	1.15	1.25	1.17	53	47	46	47	54	46	46										0955
26	.51	.66	1.17	.62	.56	1.18	.48	.54	1.02	.54	.56	1.10	1.10	1.14	50	49	50	50	50	48	48	47									0900
28	.61	.63	1.24	.64	.56	1.20	.50	.52	1.02	.53	.56	1.09	1.13	1.14	38	43	46	49	35	42	44	44	.33	.33							0950
29	.76	.68	1.44	.61	.56	1.17	.56	.56	1.12	.54	.57	1.11	1.28	1.14	38	41	42	43	36	39	41	40	.02	.02							0855
30	.70	.68	1.38	.61	.56	1.17	.56	.60	1.16	.54	.57	1.11	1.27	1.14																	
Mean	.69	.71	1.40	.63	.57	1.20	.61	.66	1.27	.61	.58	1.19	1.33	1.20				41.8				45.5									
																				Total			.63	.63							
May																															
3	.63	.70	1.33	.61	.56	1.17	.57	.64	1.21	.56	.58	1.14	1.27	1.16	31	34	37	39	31	33	34	34	T	T							0855
5	.63	.68	1.31	.61	.56	1.17	.57	.62	1.19	.55	.58	1.13	1.25	1.15	48	42	42	42	52	40	41	40									0850
7	.60	.66	1.26	.60	.56	1.16	.51	.58	1.09	.52	.56	1.08	1.18	1.12	54	48	48	49	54	47	48	46	.10	.10							0840
10	.50	.61	1.11	.58	.55	1.13	.44	.50	.94	.50	.55	1.05	1.03	1.09	54	54	54	54	54	52	54	51									0850
12	.43	.56	.99	.54	.54	1.08	.38	.46	.84	.48	.54	1.02	.92	1.05	64	58	57	57	68	58	57	54									0845
14	.34	.50	.84	.51	.51	1.02	.32	.44	.76	.46	.53	.99	.80	1.00	64	62	62	62	66	60	61	59									0835
17	.29	.44	.73	.48	.43	.91	.32	.40	.72	.44	.51	.95	.73	.93	63	59	59	59	66	56	58	56									0840
19	.27	.40	.67	.44	.37	.81	.29	.39	.68	.43	.49	.92	.68	.86	72	63	62	62	75	53	62	59									0950
21	.23	.36	.59	.32	.30	.62	.28	.37	.65	.39			.62		69	69	69	68	69	69	69										0845
23	.28	.34	.62	.29	29	.58	.47	.37	.84	.38	.42	.80	.73	.69	59	59	59	61	56	55	57	56	.27	.27							1015
24	.30	.34	.64	.28	.28	.56	.48	.36	.84	.38	.41	.79	.74	.68	58	54	56	58	61	53	54	54									0850
27	.29	.32	.61	.26	.26	.52	.45	.36	.81	.34	.34	.68	.71	.60	57	56	58	59	56	54	54	54	.09 3/	.09 3/							0840
28	.29	.32	.61	.25	.26	.51	.46	.36	.82	.35	.33	.66	.72	.59	52	54	56	57	50	53	54	53	.15	.15							1420
Mean	.39	.48	.87	.44	.42	.86	.43	.45	.88	.44	.49	.93	.88	.91				60.6				51.3									
																				Total			.62	.62							

[1] a = artificial precipitation
2 Corrected values from intensity gage
3/ 5/25/54

Table 10.--Meteorological and soil factors, Highway site,

June, 1954.

RI-INT
Infiltration Project

HYDROMETEOROLOGICAL FACTORS

SITE HIGHWAY

DATE	SOIL MOISTURE														SOIL TEMPERATURE								PRECIPITATION[1]		AIR TEMPERATURE				RELATIVE HUMIDITY	WIND VELOCITY	TIME
	TIER 1						TIER 2						SITE MEANS		TIER 1				TIER 2												
	Soil Depth (Inches)						Soil Depth (Inches)								Soil Depth (Inches)				Soil Depth (Inches)												
1954	0-3	3-6	0-6	6-9	9-12	6-12	0-3	3-6	0-6	6-9	9-12	6-12	0-6	6-12	1-1/2	4-1/2	7-1/2	10-1/2	1-1/2	4-1/2	7-1/2	10-1/2	TIER 1	TIER 2	MAXIMUM	MINIMUM	MEAN	DEG. DAYS			
	(Inches)														(Degrees F)								(Inches)		(Degrees F)				(%)	(mph)	(Hours)
June																															
1	.29	.30	.59	.22	.24	.46	.36	.35	.71	.29	.30	.59	.65	.53	63	61	61	61	63	59	59	58									0835
2	.82	.69	1.51	.48	.24	.72	.95	.74	1.69	.29	.31	.60	1.59	.66	48	50	53	55	47	48	50	51	1.04	1.04							0900
3	.77	.68	1.45	.48	.24	.72	.95	.75	1.70	.48	.30	.78	1.58	.75	54	51	53	54	54	49	50	50									0840
6	.77	.66	1.43	.48	.24	.72	.81	.64	1.45	.46	.30	.76	1.44	.74	63	59	59	59	63	59	58	55	.32	.32							1035
7	.68	.66	1.34	.49	.24	.73	.68	.63	1.31	.46	.30	.76	1.33	.75	57	56	58	59	56	54	54	54									0840
9	.50	.56	1.06	.48	.24	.72	.56	.47	1.03	.45	.30	.75	1.05	.74	64	61	61	63	65	59	59	58									0840
11	.75	.68	1.43	.50	.25	.75	.75	.66	1.41	.45	.31	.76	1.42	.76	61	59	60	61	62	58	58	57	.56	.56							0845
14	.45	.53	.98	.48	.24	.72	.52	.45	.97	.44	.30	.74	.98	.73	69	68	68	68	69	66	66	64									0835
15	.31	.47	.78	.44	.24	.68	.41	.40	.81	.42	.30	.72	.80	.70	83	77	71	69	84	77	73	67									1430
16	.32	.45	.77	.42	.24	.66	.41	.39	.80	.41	.31	.72	.79	.69	72	67	67	68	78	66	66	65									1205
18	.30	.42	.72	.34	.24	.58	.39	.37	.76	.38	.30	.68	.74	.63	68	63	63	64	71	60	61	60									0925
21	.24	.33	.57	.25	.23	.48	.29	.34	.63	.26	.28	.54	.60	.51	73	69	69	69	77	69	69	68									0855
22	.20	.30	.50	.23	.22	.45	.31	.33	.64	.24	.27	.51	.57	.48	86	71	70	70	94	71	70	68									1030
23	.89	.73	1.62	.22	.23	.45	.86	.80	1.66	.26	.28	.54	1.64	.50	76	72	71	70	71	70	70	68	1.20[a]	1.20[a]							1325
24	.94	.88	1.82	.72	.57	1.29	.97	.86	1.83	.76	.28	1.04	1.83	1.17	67	69	69	70	64	66	68	66	1.08[a]	.60[a]							0650
25	1.25	1.42	2.67	1.50	1.47	2.97	1.26	1.36	2.62	1.46	1.38	2.84	2.65	2.91	73	73	71	70	74	73	71	68	.16[2/]	.16[2/]							1515
26	.99	1.04	2.03	1.14	1.09	2.23	1.10	1.04	2.14	1.01	.96	1.97	2.09	2.10	66	66	68	69	67	65	66	65									0800
28	.97	.99	1.96	1.10	.99	2.09	1.05	1.00	2.05	.96	.93	1.89	2.01	1.99	73	68	68	68	78	68	68	65									1000
29	.96	.98	1.94	1.09	.98	2.07	1.01	.97	1.98	.94	.93	1.87	1.96	1.97	59	63	65	67	58	61	63	63	.04	.04							0900
30	.93	.96	1.89	1.04	.98	2.02	.87	.93	1.80	.90	.91	1.81	1.85	1.92	80	70	67	65	83	70	67	62									1430
Mean	.67	.69	1.35	.61	.49	1.06	.73	.67	1.40	.57	.48	1.04	1.38	1.08				64.9				61.6									
																				Total			4.40	3.92							

[1]a=artificial precipitation

2/ 6/25/54

Table 11.--Meteorological and soil factors, Highway site,
July and August, 1954.

HYDROMETEOROLOGICAL FACTORS

SITE HIGHWAY

DATE	SOIL MOISTURE														SOIL TEMPERATURE								PRECIPITATION[1]		AIR TEMPERATURE				RELATIVE HUMIDITY	WIND VELOCITY	TIME
	TIER 1						TIER 2						SITE MEANS		TIER 1				TIER 2												
	Soil Depth (Inches)						Soil Depth (Inches)								Soil Depth (Inches)				Soil Depth (Inches)												
1954	0-3	3-6	0-6	6-9	9-12	6-12	0-3	3-6	0-6	6-9	9-12	6-12	0-6	6-12	1-1/2	4-1/2	7-1/2	10-1/2	1-1/2	4-1/2	7-1/2	10-1/2	TIER 1	TIER 2	MAXIMUM	MINIMUM	MEAN	DEG. DAYS			
July	(Inches)														(Degrees F)								(Inches)		(Degrees F)				(%)	(mph)	(Hours)
1	.92	.95	1.87	1.02	.96	1.98	.87	.91	1.78	.89	.90	1.79	1.83	1.89	60	62	64	65	60	61	62	62									0910
2	.91	.92	1.83	.96	.95	1.91	.80	.87	1.67	.84	.86	1.70	1.75	1.81	62	63	64	65	61	61	62	62									0835
7	.57	.76	1.33	.76	.76	1.52	.68	.58	1.26	.61	.85	1.46	1.30	1.49	72	73	74	75	74	74	74	73									0800
9	.43	.62	1.05	.64	.69	1.33	.58	.48	1.06	.52	.78	1.30	1.06	1.32	86	78	77	77	97	80	80	76	.04	.04							1055
14	.25	.44	.69	.50	.53	1.03	.39	.40	.79	.45	.56	1.01	.74	1.02	87	80	80	80	97	80	80	79									1030
15	.28	.42	.70	.49	.52	1.01	.34	.40	.74	.45	.54	.99	.72	1.00	80	78	79	80	77	76	79	78	.16	.16							0850
16	.31	.40	.71	.47	.49	.96	.39	.39	.78	.44	.52	.96	.75	.96	78	80	80	80	74	79	80	79									0700
19	.56	.50	1.06	.44	.44	.88	.59	.42	1.01	.44	.50	.94	1.04	.91	74	77	79	80	73	74	77	76	.74 2/	.74 2/							0830
21	.48	.45	.93	.43	.39	.82	.49	.41	.90	.43	.49	.92	.92	.87	78	80	80	80	74	79	80	78									0625
23	.27	.41	.68	.38	.35	.73	.38	.40	.78	.42	.48	.90	.73	.82	66	73	76	79	61	69	73	74									0620
26	.25	.35	.60	.31	.30	.61	.28	.38	.66	.40	.43	.83	.63	.72	81	80	80	80	86	80	80	78									0835
28	.20	.33	.53	.29	.28	.57	.28	.37	.65	.40	.40	.80	.59	.69	81	80	80	80	83	80	80	80									0830
30	.20	.32	.52	.26	.26	.52	.27	.36	.63	.38	.37	.75	.58	.64	78	78	79	80	80	77	79	77	.01	.01							0830
Mean	.43	.53	.96	.53	.53	1.07	.49	.49	.98	.51	.59	1.10	.97	1.09				77.0				74.8									
																				Total			.95	.95							
Aug.																															
3	.20	.28	.48	.23	.21	.44	.27	.35	.62	.34	.32	.66	.55	.55	94	91	86	83	92	89	86	81									1920
4	.56	.29	.85	.24	.22	.46	.76	.35	1.11	.34	.33	.67	.98	.57	74	74	78	80	74	73	74	74	.59	.59							0845
6	.91	.30	1.21	.23	.23	.46	.81	.34	1.15	.34	.33	.67	1.18	.57	69	69	70	73	69	68	69	69	.57	.57							0815
9	.50	.42	.92	.25	.23	.48	.52	.36	.88	.34	.33	.67	.90	.58	72	71	73	74	76	70	71	70									0850
11	.39	.39	.78	.26	.24	.50	.36	.36	.72	.32	.32	.64	.75	.57	79	76	76	77	83	74	76	74									0820
12	.33	.38	.71	.26	.24	.50	.38	.30	.68	.34	.32	.66	.70	.58	74	74	76	78	74	73	74	74	.22	.22							0845
13	.68	.36	1.04	.26	.24	.50	.55	.36	.91	.32	.32	.64	.98	.57	74	74	74	77	73	72	74	73	.18	.18							0835
16	.51	.34	.85	.26	.24	.50	.63	.36	.99	.32	.33	.65	.92	.58	76	71	72	74	80	70	71	70	.42	.42							0930
17	.90	.78	1.68	.28	.24	.52	.57	.36	.93	.32	.32	.64	1.31	.58	66	67	69	71	64	64	67	68	.58	.58							0845
20	.55	.64	1.19	.50	.24	.74	.53	.44	.97	.34	.32	.66	1.08	.70	89	78	74	72	94	79	76	71									1330
21	.50	.60	1.10	.50	.24	.74	.49	.44	.93	.35	.33	.68	1.02	.71	74	71	71	72	77	70	70	69	.05	.05							0945
23	.46	.52	.98	.50	.25	.75	.46	.42	.88	.35	.33	.68	.93	.72	69	69	69	71	71	68	69	69									0850
26	.30	.46	.76	.47	.26	.73	.32	.38	.70	.35	.33	.68	.73	.71	73	72	73	74	73	70	72	70									0830
27	.30	.44	.74	.45	.26	.71	.30	.37	.67	.34	.33	.67	.71	.69	65	69	69	72	65	66	69	69									0820
Mean	.51	.44	.95	.33	.24	.57	.50	.37	.90	.34	.33	.66	.91	.62				74.9				71.5									
																				Total			2.61	2.61							

[1] a = artificial precipitation

2/ 7/17/54

Table 12.--Meteorological and soil factors, Gumbo site,

April and May, 1954.

RI – INT
Infiltration Project

HYDROMETEOROLOGICAL FACTORS

SITE GUMBO

DATE	SOIL MOISTURE														SOIL TEMPERATURE								PRECIPITATION[1]		AIR TEMPERATURE				RELATIVE HUMIDITY	WIND VELOCITY	TIME
	TIER 1						TIER 2						SITE MEANS		TIER 1				TIER 2												
	Soil Depth (Inches)						Soil Depth (Inches)								Soil Depth (Inches)				Soil Depth (Inches)												
1954	0-3	3-6	0-6	6-9	9-12	6-12	0-3	3-6	0-6	6-9	9-12	6-12	0-6	6-12	1-1/2	4-1/2	7-1/2	10-1/2	1-1/2	4-1/2	7-1/2	10-1/2	TIER 1	TIER 2	MAXIMUM	MINIMUM	MEAN	DEG. DAYS			
April	(Inches)														(Degrees F)								(Inches)		(Degrees F)				(%)	(mph)	(Hours)
6	1.26	1.25	2.51	1.15	.61	1.76	1.24	1.36	2.60	.86	.65	1.51	2.56	1.66	46	42	40	39	50	42	42	40									1315
7	1.14	1.16	2.30	1.08	.58	1.66	1.13	1.29	2.42	1.09	.65	1.74	2.36	1.70	38	38	37	38	42	37	38	38									1055
12	1.06	1.08	2.14	.97	.58	1.55	.97	1.27	2.24	.87	.65	1.52	2.19	1.54	66	54	46	42	73	54	46	42									1420
14	.99	1.08	2.07	.96	.58	1.54	.95	1.20	2.15	.99	.65	1.64	2.11	1.59	57	53	54	50	59	53	50	50									1115
15	.96	1.08	2.04	.97	.58	1.55	.92	1.18	2.10	.97	.65	1.62	2.07	1.58	46	46	46	47	48	46	46	47	.08	.08							1035
16	.94	1.06	2.00	.96	.58	1.54	.83	1.17	2.00	.97	.65	1.62	2.00	1.58																	1335
18	.88	1.03	1.91	.93	.58	1.51	.83	1.14	1.97	.98	.65	1.63	1.94	1.57	43	44	43	45	44	43	44	45	.11	.11							1000
19	.86	1.03	1.89	.92	.58	1.50	.81	1.12	1.93	.95	.65	1.60	1.91	1.55									T	T							1410
21	.85	1.03	1.88	.91	.58	1.49	.78	1.11	1.89	.91	.65	1.56	1.88	1.52	42	38	38	42	46	38	39	32	T	T							0930
23	.82	1.03	1.85	.93	.58	1.51	.65	1.10	1.75	.87	.65	1.52	1.80	1.52	52	47	46	46	54	48	46	46									0920
26	.76	.98	1.74	.84	.58	1.42	.60	1.06	1.66	.85	.65	1.50	1.70	1.46	50	48	47	48	53	47	47	48									0925
28	.70	.96	1.66	.83	.58	1.41	.61	1.02	1.63	.88	.65	1.53	1.64	1.47	38	42	43	46	36	42	45	46	.39	.39							1020
29	.72	.96	1.68	.82	.58	1.40	.62	1.01	1.63	.84	.65	1.49	1.66	1.44	36	38	39	42	36	38	41	42	.02	.02							0930
30	.71	.96	1.67	.81	.58	1.39	.63	1.02	1.65	.84	.65	1.49	1.66	1.44																	1335
Mean	.90	1.05	1.95	.93	.58	1.52	.83	1.15	1.97	.92	.65	1.57	1.96	1.54				44.1				43.3									
																				Total			.60	.60							
May																															
3	.68	.94	1.62	.79	.58	1.37	.81	1.05	1.86	.83	.65	1.48	1.74	1.42	32	34	34	38	32	34	35	38	T	T							0935
5	.70	.93	1.63	.78	.58	1.36	.88	1.05	1.93	.81	.65	1.46	1.78	1.41	46	42	40	42	50	41	41	42									0915
7	.67	.92	1.59	.78	.58	1.36	.76	1.03	1.79	.80	.65	1.45	1.69	1.40	52	48	46	46	54	49	46	47	.12	.12							0930
10	.63	.89	1.52	.75	.58	1.33	.61	.96	1.57	.79	.65	1.44	1.54	1.38	53	52	50	51	55	52	52	51									0915
12	.60	.87	1.47	.69	.58	1.27	.57	.88	1.45	.78	.65	1.43	1.46	1.35	61	57	54	54	69	57	54	54									0920
14	.57	.85	1.42	.60	.58	1.18	.55	.77	1.32	.74	.65	1.39	1.37	1.28	61	59	58	58	66	59	59	59									1900
17	.52	.74	1.26	.59	.58	1.17	.53	.71	1.24	.69	.65	1.34	1.25	1.26	60	57	54	57	66	58	55	56									0920
19	.48	.67	1.15	.59	.58	1.17	.48	.70	1.18	.66	.66	1.32	1.16	1.24	66	60	59	59	74	62	59	59									1010
21	.46	.62	1.08	.59	.59	1.18	.47	.69	1.16	.64	.65	1.29	1.12	1.24	69	68	64	63	69	68	64	63	.18	.18							0915
23	.47	.61	1.08	.59	.59	1.18	.56	.69	1.25	.61	.66	1.27	1.16	1.22	55	55	54	58	55	54	55	57	.23	.23							1040
24	.47	.61	1.08	.59	.59	1.18	.55	.69	1.24	.60	.66	1.26	1.16	1.22	56	52	52	54	63	53	52	54	.02	.02							0925
27	.50	.60	1.10	.59	.59	1.18	.57	.68	1.25	.59	.66	1.25	1.18	1.22	56	54	53	56	59	54	54	56	.17[2/]	.17[2/]							0915
28	.51	.59	1.10	.59	.59	1.18	.58	.68	1.26	.59	.66	1.25	1.18	1.22	52	53	52	54	50	52	52	54	.22	.22							1450
Mean	.56	.76	1.31	.66	.59	1.24	.61	.81	1.42	.70	.65	1.36	1.37	1.30				53.1				53.1									
																				Total			.94	.94							

[1]a=artificial precipitation
2/ 5/25/54

Table 13.--Meteorological and soil factors, Gumbo site,

June, 1954.

RI – INT
Infiltration Project

HYDROMETEOROLOGICAL FACTORS

SITE GUMBO

DATE	SOIL MOISTURE														SOIL TEMPERATURE								PRECIPITATION[1]		AIR TEMPERATURE				RELATIVE HUMIDITY	WIND VELOCITY	TIME
	TIER 1						TIER 2						SITE MEANS		TIER 1				TIER 2												
	Soil Depth (Inches)						Soil Depth (Inches)								Soil Depth (Inches)				Soil Depth (Inches)				TIER 1	TIER 2	MAXIMUM	MINIMUM	MEAN	DEG. DAYS			
1954	0-3	3-6	0-6	6-9	9-12	6-12	0-3	3-6	0-6	6-9	9-12	6-12	0-6	6-12	1-1/2	4-1/2	7-1/2	10-1/2	1-1/2	4-1/2	7-1/2	10-1/2									
June	(Inches)														(Degrees F)								(Inches)		(Degrees F)				(%)	(mph)	(Hours)
1	.50	.58	1.08	.59	.59	1.18	.56	.68	1.24	.58	.66	1.24	1.16	1.21	60	59	57	58	62	59	58	58									0900
2	1.26	.58	1.84	.59	.59	1.18	1.03	.68	1.71	.58	.66	1.24	1.78	1.21	47	50	52	54	48	50	52	54	1.03	1.03							0935
3	1.19	.59	1.78	.59	.59	1.18	1.10	.69	1.79	.58	.66	1.24	1.78	1.21	52	50	50	52	56	50	50	52	.01	.01							0910
6	1.23	.62	1.85	.59	.59	1.18	1.10	.69	1.79	.58	.66	1.24	1.82	1.21	59	58	55	56	62	59	56	57	.34	.34							1100
7	1.06	.63	1.69	.59	.59	1.18	1.10	.69	1.79	.58	.66	1.24	1.74	1.21	54	53	54	56	56	54	54	56									0905
9	.81	.64	1.45	.59	.59	1.18	1.05	.69	1.74	.58	.65	1.23	1.60	1.20	60	59	57	59	63	59	58	59									0900
11	1.14	.64	1.78	.59	.59	1.18	1.10	.69	1.79	.58	.66	1.24	1.78	1.21	59	58	56	59	63	59	58	59	.47	.47							0920
14	.67	.64	1.31	.59	.59	1.18	1.09	.69	1.78	.58	.66	1.24	1.54	1.21	66	64	63	63	69	65	63	63									0905
15	.59	.60	1.19	.59	.59	1.18	.86	.68	1.54	.58	.65	1.23	1.36	1.20	80	74	68	63	82	77	68	64									1515
16	.58	.60	1.18	.59	.59	1.18	.78	.68	1.46	.58	.65	1.23	1.32	1.20	69	68	64	63	69	69	64	63									1550
18	.56	.61	1.17	.59	.59	1.18	.61	.68	1.29	.57	.65	1.22	1.23	1.20	60	59	59	60	65	60	60	60									0845
21	.50	.58	1.08	.59	.59	1.18	.39	.67	1.06	.57	.65	1.22	1.07	1.20	71	69	65	66	80	69	66	66									0930
22	.48	.57	1.05	.59	.59	1.18	.41	.67	1.08	.57	.65	1.22	1.06	1.20	81	71	65	64	94	74	66	65									1135
23	.52	.58	1.10	.59	.59	1.18	.97	.75	1.72	.57	.65	1.22	1.41	1.20	69	69	69	69	69	68	66	66	.90[a]	.48[a]							0810
24	1.48	1.36	2.84	1.25	.59	1.84	1.30	1.32	2.62	1.09	.80	1.89	2.73	1.86	64	68	68	69	64	65	66	66	1.80[a]	1.20[a]							0710
26	1.66	1.54	3.20	1.46	.68	2.14	1.66	1.60	3.26	1.47	1.31	2.78	3.23	2.46	61	65	65	66	61	62	64	65	.16[2/]	.16[2/]							0730
28	1.66	1.51	3.17	1.42	.93	2.35	1.42	1.43	2.85	1.25	1.11	2.36	3.01	2.36	61	65	65	66	61	62	64	64									0640
29	1.62	1.42	3.04	1.50	1.00	2.50	1.26	1.40	2.66	1.21	1.03	2.24	2.85	2.37	61	61	61	63	61	62	62	63	.03	.03							1230
30	1.40	1.28	2.68	1.14	.97	2.11	1.14	1.35	2.49	1.14	1.02	2.16	2.58	2.14	68	60	59	60	73	62	60	60									1035
Mean	.99	.82	1.81	.79	.65	1.44	1.00	.88	1.88	.75	.76	1.51	1.84	1.48				61.4				61.1									
																				Total			4.74	3.72							

[1]a = artificial precipitation

2/ 6/25/54

Table 14.--Meteorological and soil factors, Gumbo site,

July and August, 1954.

RI– INT
Infiltration Project

HYDROMETEOROLOGICAL FACTORS

SITE GUMBO

DATE	SOIL MOISTURE														SOIL TEMPERATURE								PRECIPITATION[1]		AIR TEMPERATURE				RELATIVE HUMIDITY	WIND VELOCITY	TIME
	TIER 1						TIER 2						SITE MEANS		TIER 1				TIER 2												
	Soil Depth (Inches)						Soil Depth (Inches)								Soil Depth (Inches)				Soil Depth (Inches)				TIER 1	TIER 2	MAXIMUM	MINIMUM	MEAN	DEG. DAYS			
1954	0-3	3-6	0-6	6-9	9-12	6-12	0-3	3-6	0-6	6-9	9-12	6-12	0-6	6-12	1-1/2	4-1/2	7-1/2	10-1/2	1-1/2	4-1/2	7-1/2	10-1/2									
July	(Inches)														(Degrees F)								(Inches)		(Degrees F)				(%)	(mph)	(Hours)
1	1.33	1.24	2.57	1.14	.96	2.10	1.11	1.35	2.46	1.16	1.02	2.18	2.52	2.14	59	60	60	61	60	61	62	62									0955
2	1.26	1.22	2.48	1.14	.96	2.10	1.08	1.33	2.41	1.15	1.01	2.16	2.44	2.13	59	60	60	62	61	63	63	63									0855
7	.94	1.12	2.06	.95	.89	1.84	.69	.72	1.41	1.14	.89	2.03	1.74	1.94	84	79	74	74	94	80	74	73									1015
9	.85	1.13	1.98	1.04	.87	1.91	.59	.69	1.28	.94	.87	1.81	1.63	1.86	94	84	80	78	101	87	80	78	.01	.01							1335
14	.65	1.11	1.76	.90	.81	1.71	.39	.68	1.07	.83	.79	1.62	1.42	1.66	87	80	79	79	101	84	80	80									1225
15	.58	1.03	1.61	.88	.72	1.60	.55	.68	1.23	.85	.80	1.65	1.42	1.62	77	77	75	79	81	77	75	78	.15	.15							0920
16	.60	1.02	1.62	.86	.76	1.62	.55	.68	1.23	.83	.78	1.61	1.42	1.62	80	80	78	79	85	80	80	80									0840
19	.65	1.02	1.67	.87	.70	1.57	.61	.68	1.29	.85	.76	1.61	1.48	1.59	74	77	77	79	75	75	77	78	.40[2]	.40[2]							0855
21	.68	1.00	1.68	.88	.70	1.58	.57	.68	1.25	.79	.74	1.53	1.46	1.56	80	78	75	77	85	79	75	77									0855
23	.58	1.00	1.58	.85	.70	1.55	.52	.68	1.20	.76	.71	1.47	1.39	1.51	69	69	70	74	74	69	71	74									0805
26	.49	1.00	1.49	.82	.69	1.51	.46	.67	1.13	.72	.68	1.40	1.31	1.46	82	80	77	79	90	80	78	79									0905
28	.47	.99	1.46	.82	.69	1.51	.44	.66	1.10	.68	.68	1.36	1.28	1.44	82	80	77	79	94	80	79	80									0945
30	.42	.97	1.39	.74	.69	1.43	.43	.66	1.09	.66	.68	1.34	1.24	1.38	79	74	74	75	81	77	74	77	.01	.01							0900
Mean	.73	1.06	1.80	.91	.78	1.69	.61	.78	1.40	.87	.80	1.67	1.60	1.68				75.0				75.3									
																				Total			.57	.57							
Aug.																															
3	.38	.92	1.30	.89	.67	1.56	.40	.66	1.06	.63	.68	1.31	1.18	1.44	80	80	80	79	82	85	80	79									1935
4	.39	.91	1.30	.77	.67	1.44	.42	.66	1.08	.63	.68	1.31	1.19	1.38	77	74	74	75	80	77	74	75	.15	.15							0950
6	.44	.88	1.32	.66	.67	1.33	.48	.66	1.14	.62	.68	1.30	1.23	1.32	71	69	69	72	73	69	69	71	.31	.31							0905
9	.52	.86	1.38	.64	.66	1.30	.48	.67	1.15	.61	.68	1.29	1.26	1.30	75	72	72	74	80	73	71	73									0910
11	.44	.85	1.29	.64	.66	1.30	.44	.67	1.11	.60	.68	1.28	1.20	1.29	81	75	74	74	88	77	73	73									1005
12	.42	.84	1.26	.65	.66	1.31	.45	.66	1.11	.60	.68	1.28	1.18	1.30	74	74	73	74	74	74	73	74	.20	.20							0915
13	.44	.83	1.27	.64	.66	1.30	.50	.66	1.16	.60	.68	1.28	1.22	1.29	74	73	73	74	75	73	73	74	.26	.26							0905
16	.85	.82	1.67	.67	.66	1.33	.54	.67	1.21	.60	.68	1.28	1.44	1.30	74	71	70	73	78	71	69	72	.38	.38							1015
17	.97	1.22	2.19	1.10	.66	1.76	1.15	.67	1.82	.94	.94	1.88	2.00	1.82	65	66	68	70	69	66	68	69	.76	.76							0908
20	.91	1.33	2.24	1.00	.66	1.66	.84	.68	1.52	.65	.68	1.33	1.88	1.50	85	78	73	72	90	80	73	72									1345
21	.88	1.31	2.19	1.02	.66	1.68	.70	.69	1.39	.64	.68	1.32	1.79	1.50	73	71	71	73	75	73	71	72	.06	.06							1010
23	.83	1.36	2.19	1.04	.66	1.70	.63	.70	1.33	.64	.68	1.32	1.76	1.51	69	69	69	70	74	69	69	71									0910
26	.76	1.35	2.11	1.03	.66	1.69	.56	.71	1.27	.63	.68	1.31	1.69	1.50	72	71	70	73	74	72	71	72									0850
27	.74	1.36	2.10	.93	.66	1.59	.55	.70	1.25	.62	.68	1.30	1.68	1.44	69	69	69	72	69	69	69	70									0845
30	.64	1.39	2.03	1.03	.66	1.69	.51	.52	1.03	.61	.66	1.27	1.53	1.48	74	73	70	72	77	72	71	73									0850
Mean	.64	1.08	1.72	.85	.66	1.51	.58	.67	1.24	.64	.70	1.34	1.48	1.43				73.1				72.7									
																				Total			2.12	2.12							

[1] a = artificial precipitation

2/ 7/17/54

Approximately two-thirds of the storms occurred as general rains of rather steady intensity, averaging about 0.10 inch per hour. The remaining storms, chiefly summer thundershowers, occurred as short duration but rather high intense rainfall. Figure 4 shows intensity-duration graphs for five summer storms during the study period. The highest intensity observed was 4.20 inches per hour for two minutes (fig. 4B). An intensity of 3.90 inches per hour occurred for 4 minutes (fig. 4A) and 2.30 for 6 minutes (fig. 4C). An intensity of 2.04 inches per hour occurred for 10 minutes at the beginning of the storm of July 7 (fig. 4D). This storm ended with a 98-minute period of 0.10 inch per hour rainfall. Minor corrections in gage catch were not made in figure 4 data. Hence the storm totals vary slightly from the amounts shown in tables 9-11, inclusive.

Air Temperature

April-August, 1954 mean monthly air temperatures at Miles City ranged from 3.7° F. below normal to 2.7° F. above (table 15). Thus the average air temperatures during the period of study did not differ markedly from the normal temperature climate. Mean monthly temperatures during the study period ranged from a low of 42.3° F. in April to a high of 77.7° F. in July.

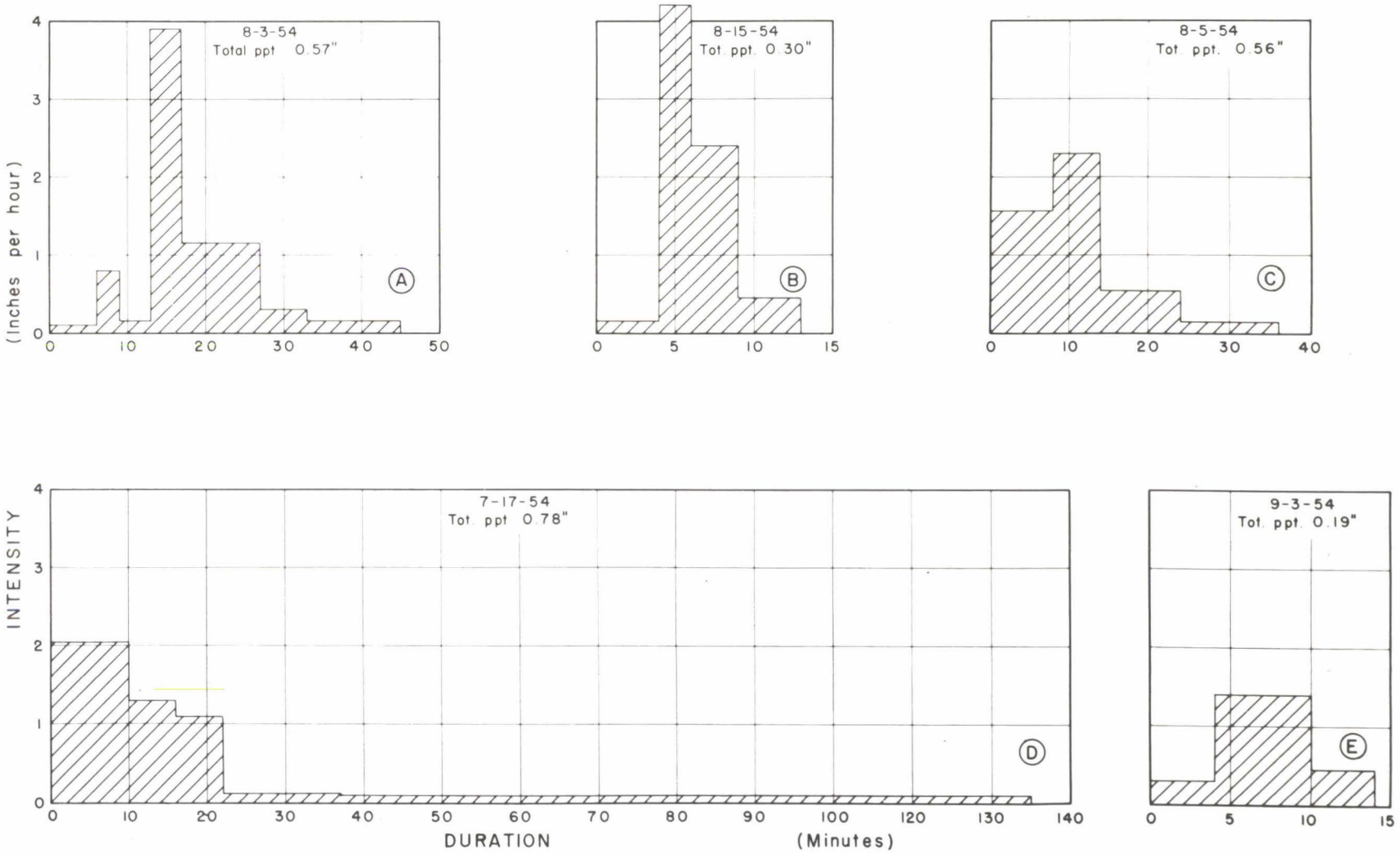

Figure 4.--Rainfall intensity-duration graphs, Highway site, 1954. Storms of: A, August 3; B, August 15; C, August 5; D, July 17; E, September 3.

Table 15.--Air temperature, CAA Miles City Airport[1/]

Day	April			May			June			July			August		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
	Degrees Fahrenheit														
1	39	14	26.5	39	24	31.5	66	38	52.0	73	50	61.5	90	55	72.5
2	20	7	13.5	35	18	26.5	52	37	44.5	75	50	62.5	91	55	73.0
3	54	14	34.0	47	15	31.0	68	37	52.5	90	49	69.5	97	63	80.0
4	66	31	48.5	61	26	43.5	80	51	65.5	100	58	79.0	79	59	69.0
5	66	36	51.0	71	30	50.5	66	48	57.0	108	66	87.0	79	61	70.0
6	53	33	43.0	62	39	50.5	62	46	54.0	98	69	83.5	79	57	68.0
7	45	28	36.5	62	37	49.5	65	44	54.5	97	64	80.5	83	54	68.5
8	63	31	47.0	64	36	50.0	73	46	59.5	104	72	88.0	89	57	73.0
9	56	31	43.5	70	45	57.5	64	44	54.0	100	68	84.0	93	57	75.0
10	52	30	41.0	66	45	55.5	70	50	60.0	103	64	83.5	91	68	79.5
11	66	25	45.5	72	50	61.0	71	47	59.0	95	62	78.5	91	57	74.0
12	76	36	56.0	79	51	65.0	81	48	64.5	104	72	88.0	93	60	76.5
13	76	42	59.0	72	52	62.0	86	54	70.0	89	66	77.5	82	60	71.0
14	61	33	47.0	72	50	61.0	76	53	64.5	94	60	77.0	88	58	73.0
15	55	33	44.0	77	41	59.0	83	49	66.0	98	68	83.0	89	55	72.0
16	75	28	51.5	67	44	55.5	66	46	56.0	93	72	82.5	83	55	69.0
17	60	38	49.0	79	45	62.0	69	43	56.0	94	63	78.5	70	52	67.0
18	48	31	39.5	75	47	61.0	76	41	58.5	98	68	83.0	81	48	64.5
19	43	29	36.0	91	52	71.5	81	45	63.0	84	65	74.5	90	52	71.0
20	52	31	41.5	89	55	72.0	78	48	63.0	95	65	80.0	87	60	73.5
21	51	22	36.5	79	57	68.0	84	58	71.0	97	62	79.5	77	57	67.0
22	65	32	48.5	60	48	54.0	103	50	76.5	80	56	68.0	79	53	66.0
23	59	34	46.5	64	43	53.5	95	62	78.5	94	52	73.0	86	55	71.0
24	64	30	47.0	70	35	52.5	89	57	73.0	93	53	73.0	97	54	75.5
25	61	41	51.0	83	52	67.5	79	56	67.5	97	61	79.0	82	60	71.0
26	65	37	51.0	66	44	55.0	86	55	70.5	100	67	83.5	98	57	77.5
27	58	29	43.5	63	38	50.5	80	60	70.0	97	63	80.0	85	49	62.0
28	37	21	29.0	51	39	45.0	81	49	65.0	91	65	78.0	80	50	65.0
29	35	22	28.5	69	35	52.0	72	48	60.0	85	58	71.5	91	53	72.0
30	42	24	33.0	59	43	51.0	75	43	59.0	82	56	69.0	100	65	82.5
31				70	32	51.0				91	51	71.0	98	65	81.5
Month	55.4	29.1	42.3	67.2	40.9	54.1	75.9	48.4	62.2	93.5	61.8	77.7	87.0	56.5	71.9
Departure from normal			-3.7			-3.0			-3.0			2.7			-0.4

1/ U.S. Weather Bureau Climatological Data, Montana Section

Mean monthly maximum April-August, 1954 air temperature was lowest in April and highest in July, 55.4 and 93.5° F., respectively. Mean monthly minimum air temperature for the same period was also lowest in April and highest in July, 29.1 and 61.8° F., respectively. The temperature extremes were a high of 108° F. on July 5 and a low of 7° F. on April 2. There were nine days during the period with air temperatures of 100° F. or higher and 23 days with temperatures below freezing.

Wind

The study area, characteristic of the plains climate, was rather windy. Mean monthly April-August wind velocity varied from 12.7 to 9.2 mph in April and August, respectively (table 16). The prevailing direction during the period was NW in April and June and SE during the remaining three months.

Table 16.--Mean monthly wind velocity and prevailing direction, CAA, Miles City Airport

	Month				
	April	May	June	July	August
Velocity (mph.)	12.7	10.7	11.0	9.5	9.2
Prevailing direction	NW	SE	NW	SE	SE

SOIL FACTORS

Instrumentation

Two tiers of fiberglas soil moisture instruments were installed at each site by the auger-hole method described by Reinhart (6) at the mid-points of 3-inch horizons, viz., 1-1/2, 4-1/2, 7-1/2, 10-1/2, 13-1/2, 16-1/2, 19-1/2, and 22-1/2 inches except that at one tier at each site additional fiberglas units were installed at 30 and 42 inches depth. The fiberglas units were calibrated by frequent gravimetric determinations of moisture content of samples taken at random from a 6-foot square sampling plot around each tier.

Soil moisture content was usually determined two or three times weekly and expressed in inches using the calibration curves for each electrical soil moisture instrument. Values by 3-inch layers were added to obtain soil moisture by the 0-6 inch and 6-12 inch depths.

Soil Moisture

The moisture content of the surface layers of soil is usually near field capacity at the beginning of the spring season. The depth of wetting depends upon the late fall and winter rainfall, which is usually rather light, and upon soil texture and structure. The moist front was from 7 to 14 inches below the surface, depending upon soil type, in April 1954. It was between 7 and 10 inches on the heavy soil of the Gumbo site. The moisture had reached from 10 to 14 inches depth on the lighter soils of the River and Highway sites. Deep soil cracking at Gumbo probably results in some deep wetting of the soil at the beginning of a rain period but the surface is soon sealed by soil swelling so that these cracks play only a minor role in extending the moist front.

Normally there would be little net loss in soil moisture until after the spring rains sometime in June. During 1954 there was approximately a one inch decrease in monthly mean moisture content of the 0-12" layer from April to May. Had rainfall been normal in May there would probably have been little change in monthly means. (table 17).

Artificial rainfall was applied to the plots on June 22 and 23, resulting in the highest moisture content of record (table 18). At Highway the soil was wetted to above field capacity to a depth of 19-1/2 inches. A similar moist front descended to an average of 18 inches at River and 12 inches at Gumbo. In one instance at Gumbo the moisture unit at 7-1/2 inches became nearly saturated immediately after application of water (movement through a crack). However, the moist front at this location never extended itself beyond the 10-1/2-inch unit.

Of the three areas tested, the moisture content in the 0-12" layer was consistently highest in the heavy soil at Gumbo. Highway was the driest site. Moisture content at River was intermediate, but somewhat nearer to Gumbo than to Highway.

Recorded soil moisture is tabulated in tables 6 through 14 and shown graphically in figures 8 to 10, inclusive.

Table 17.--Mean monthly moisture content in the 0-12 inch soil layer

Month	Site		
	River	Highway	Gumbo
	Inches		
April	3.38	2.53	3.51
May	2.36	1.79	2.67
June	1/2.68	1/1.71	1/2.69
	2/3.18	2/2.45	2/3.32
July	2.60	2.06	3.28
August	2.42	1.53	2.91

1/ June 1-20, inclusive

2/ June 1-30, inclusive, artificial rainfall applied June 22 and 23.

Table 18.--Maximum soil moisture content

Depth	Site		
	River	Highway	Gumbo
	Inches		
0-6	2.99	2.91	3.23
6-12	2.69	2.65	2.46
0-12	5.68	5.56	5.69

Soil Temperature

Mean monthly soil temperatures at 10-1/2 inches for each site are presented in table 19. River site temperatures at 10-1/2 inches were warmer for the months of April, May and June while Gumbo was the coolest for the same period. During July and August Highway site temperatures were highest and River the lowest. The greatest range occurred in May when Gumbo was 3.5° lower than River temperatures at 10-1/2 inches. The total range in temperatures at 10-1/2 inches for individual sites was around 29° for Gumbo and Highway and 25° at River.

Radiation received at the various sites is quite uniform. The greatest interception of radiation occurs at River were vegetation is heaviest. The Highway site is intermediate in shading by vegetation and Gumbo, with a square foot density of 1/10 is the least shaded. Soil temperatures at 1-1/2, 4-1/2, 7-1/2, and 10-1/2 inches are shown in tables 6 to 14.

Table 19.--Mean monthly soil temperature at the 10-1/2 inch depth 1/

Month	Site		
	River	Highway	Gumbo
	°F		
April	46.2	43.6	43.7
May	56.5	56.0	53.1
June	64.0	63.2	61.2
July	73.5	75.9	75.2
August	71.8	73.2	72.9

1/ Reading generally taken between 8:00 and 9:00 a.m.

SOIL MOISTURE ACCRETION

Increases in soil moisture content (accretion) are due to precipitation at the Miles City sites. The maximum possible soil moisture content within a given soil layer under normal field conditions is equivalent to the field capacity of the layer. Soil moisture in excess of field capacity can be stored temporarily, but such excesses pass to the soil layers below. Large soil pores and passageways such as left by rodents and insect burrows and decaying roots may pass water to the lower soil layers before the upper layers reach field capacity. Other factors influencing accretion include the intensity and duration of rainfall, interception by vegetation and ground surface litter, and the rate at which the soil can absorb rainfall.

Rainfall at each of the sites is considered throughfall because of the low density of vegetation. Infiltration, the rate at which water can pass into the soil at any given time when rainfall occurs at intensities high enough to cause runoff, was measured at the River and Highway sites by application of artificial rainfall with an infiltrometer (2). Average infiltration curves for wet runs are shown in figure 5. Dry run data are not available.

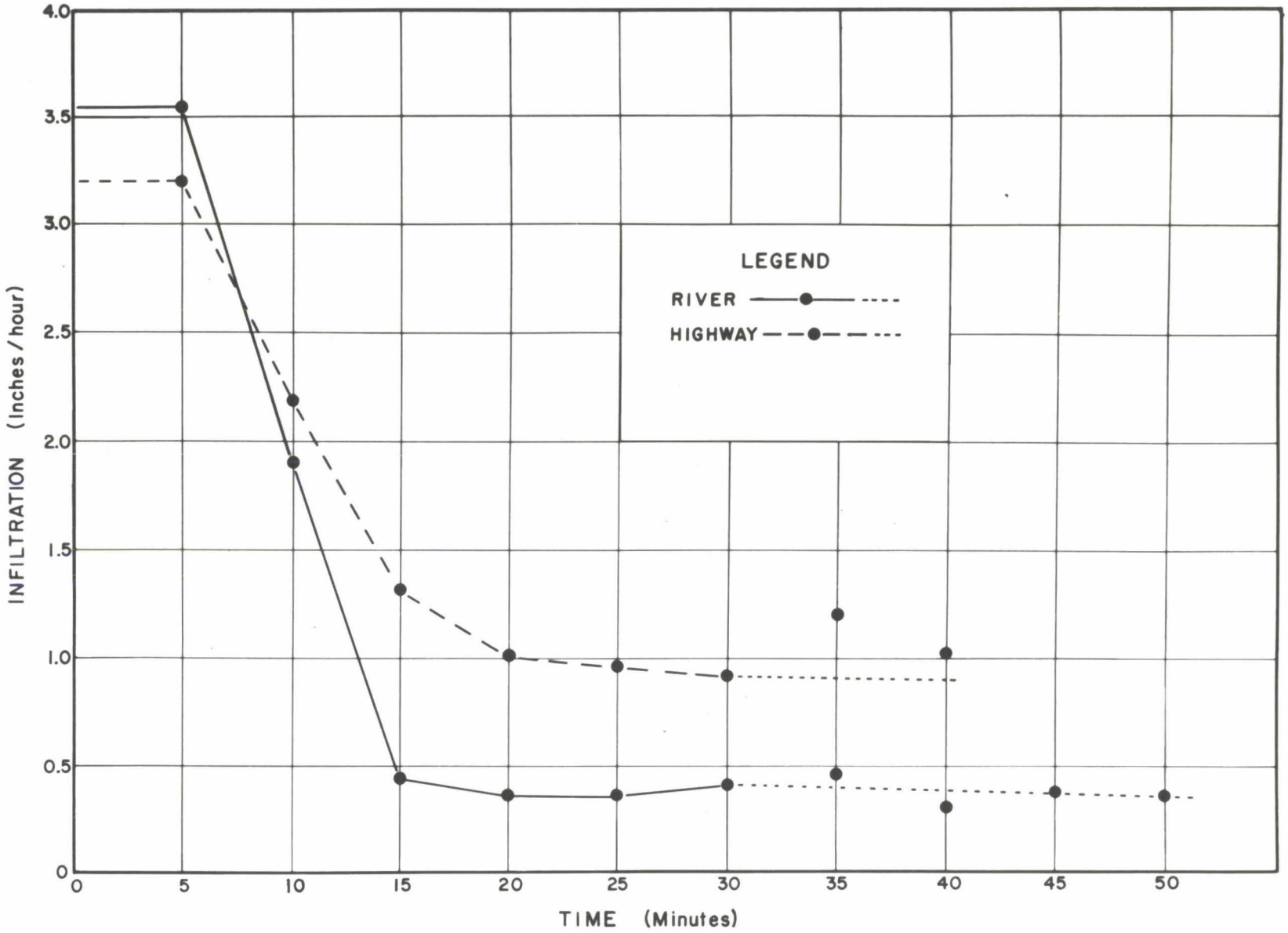

Figure 5.--Infiltration curves for River and Highway sites.

Intensities of some of the natural storms exceeded the infiltration capacity. It should be noted, however, that storms of higher intensities were brief and perhaps surface detention storage and the effects of soil cracking were sufficient to prevent or reduce surface runoff. This was not specifically studied during natural storms, however. Infiltration tests were not conducted at the Gumbo site. It is, nevertheless, a practical certainty that infiltration rates are much lower in this heavy soil than in the lighter soils of the River and Highway sites. The opportunity for considerable surface detention storage is particularly good at the Gumbo site where the soil surface microrelief is developed by cattle trampling a moist plastic soil. Also, soil cracking here is severe. Surface runoff undoubtedly occurs during the more severe storms with the plot area losing water to the slopes below but gaining it from the slopes above.

The relationship of rainfall to soil moisture was determined on the basis of space available for soil moisture storage. Available storage was determined from maximum soil moisture contents (table (table 18) which were the highest observed or calculated values, presumably field capacity.

Rainfall--available storage relationships may be differentiated into accretion classes on the basis of storm size.

Accretion Class	Definition
I	Rainfall amounts which yield accretion amounts equal to or less than the available storage in the surface foot of soil.
II	Rainfall amounts which yield accretion amounts in excess of available storage in the surface foot of soil.

Rainfall--available storage relationships for accretion Class I express accretion as a linear function of rainfall (table 20). Relationships for Class II accretion were not determined because only one Class II accretion condition was obtained and that with an artificial application of rainfall.

The maximum amount of rainfall (throughfall) which fails to result in a net soil moisture accretion is defined as the X-intercept of the accretion-precipitation regression line, and is thus the storm size for which accretion exactly balances depletion. For storm amounts in excess of this value, accretion is greater than depletion. Conversely, storm amounts less than the intercept value may add moisture to the soil but depletion exceeds the addition of water, so the result is a negative accretion or a net depletion. As rainfall amounts become smaller, the negative accretion becomes larger until with no rainfall the negative accretion theoretically is depletion uninfluenced by increments of soil moisture.

Table 20.--Relationship of soil moisture accretion to rainfall

Site	Depth Inches	Regression of accretion on rainfall
River	0-6	Y[1/] = .971 x[2/] -.144
	6-12	Y = .324 x -.056
Highway	0-6	Y = .855 x -.109
	6-12	Y = .211 x -.064
Gumbo	0-6	Y = .778 x -.137
	6-12	Y = .312 x -.085

1/ Y = estimated accretion (inches)

2/ X = rainfall (inches)

The observed soil moisture history associated with small storms indicates that their effect may vary according to the antecedent moisture content of the intercepting layer, in this case the soil and litter layer above the fiberglas unit at the 1-1/2 inch depth. Moisture of a storm of some small size might be entirely withheld by litter and upper soil layers that are considerably below field capacity. The same size storm might contribute an appreciable part of its volume to an apparent reduction of depletion rate or a net accretion when the layers above the upper fiberglas unit are near field capacity due to previous rains and low evapo-transpiration rates. The formulae of table 20 average the range of these effects.

Estimates of accretion due to rainfall are made by first determining whether the rainfall-storage relationship is Class I or Class II. Subtracting soil moisture content from the proper maximum storage value in table 18 indicates available storage. The appropriate equation solved with the rainfall amount shows the amount of accretion for Class I conditions. For Class II rainfall-storage relationships, it must be assumed, for the present, that soil moisture is brought up to the maximum value indicated in table 18. Negative accretions indicated by formula for small storms are used only if they do not exceed the depletion rate shown by the depletion curves. In other words, for storm amounts less than the X-intercept value, use the smaller of the following two values: (a) depletion amount indicated by depletion curves and (b) the negative accretion amount indicated by accretion formulae. Rainfall amounts less than .02 or .03 inch are generally ignored.

SOIL MOISTURE DEPLETION

Soil moisture depletion rates for a given soil and depth are defined largely by time and soil moisture content. Time is an integration of factors such as vegetation, evaporation, and drainage of gravitational water.

The similarity of individual depletion periods, such as those shown graphically in figures 6 to 8, inclusive, was evident when the periods were superimposed one over the other. This revealed consistently high depletion rates following the development of near maximum moisture contents in late June. Depletion rates following high moisture levels in the spring and early summer were much less. Both depletion patterns reached a minimum daily loss rate as moisture contents approached the point beyond which vegetation made little further use of soil water. The differentiation between the two depletion relationships reflects the effectiveness of spring conditions such as lower air temperatures, higher humidities, and vegetation in early stages of development as compared with higher air temperatures, lower humidities, and vegetation in stages of maximum development under summer conditions.

Depletion curves for soil moisture prediction were developed by superimposing and matching the graphs of individual soil moisture depletion periods to produce a family of curves covering the moisture range from near maximum storage to the minimum of record. Smooth curves (figures 9 and 10) averaging the depletions were drawn and reduced to tables (table 21) from which the curves can be replotted to any desired scale.

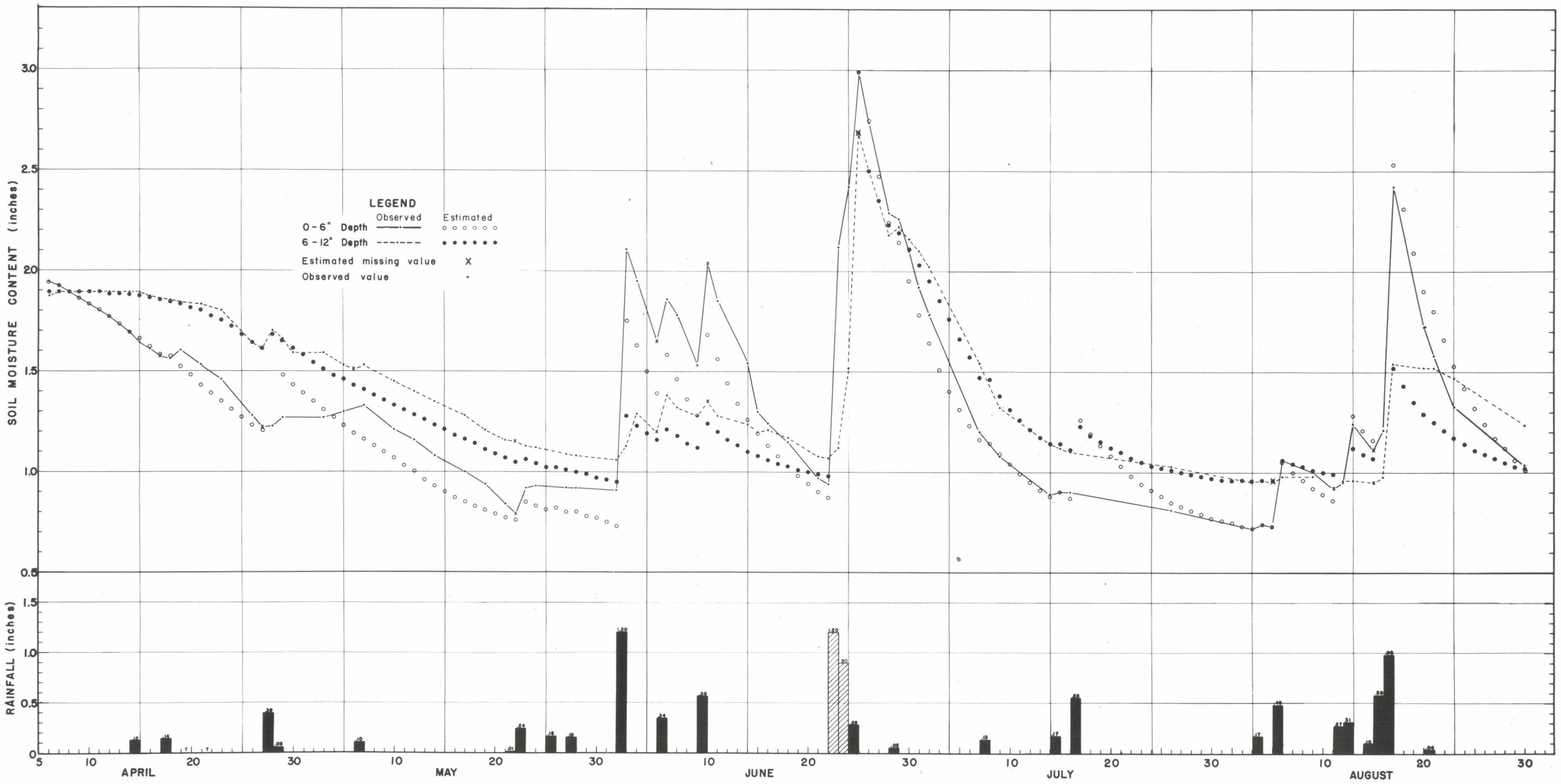

Figure 6.--Rainfall and observed and estimated soil moisture at River site.

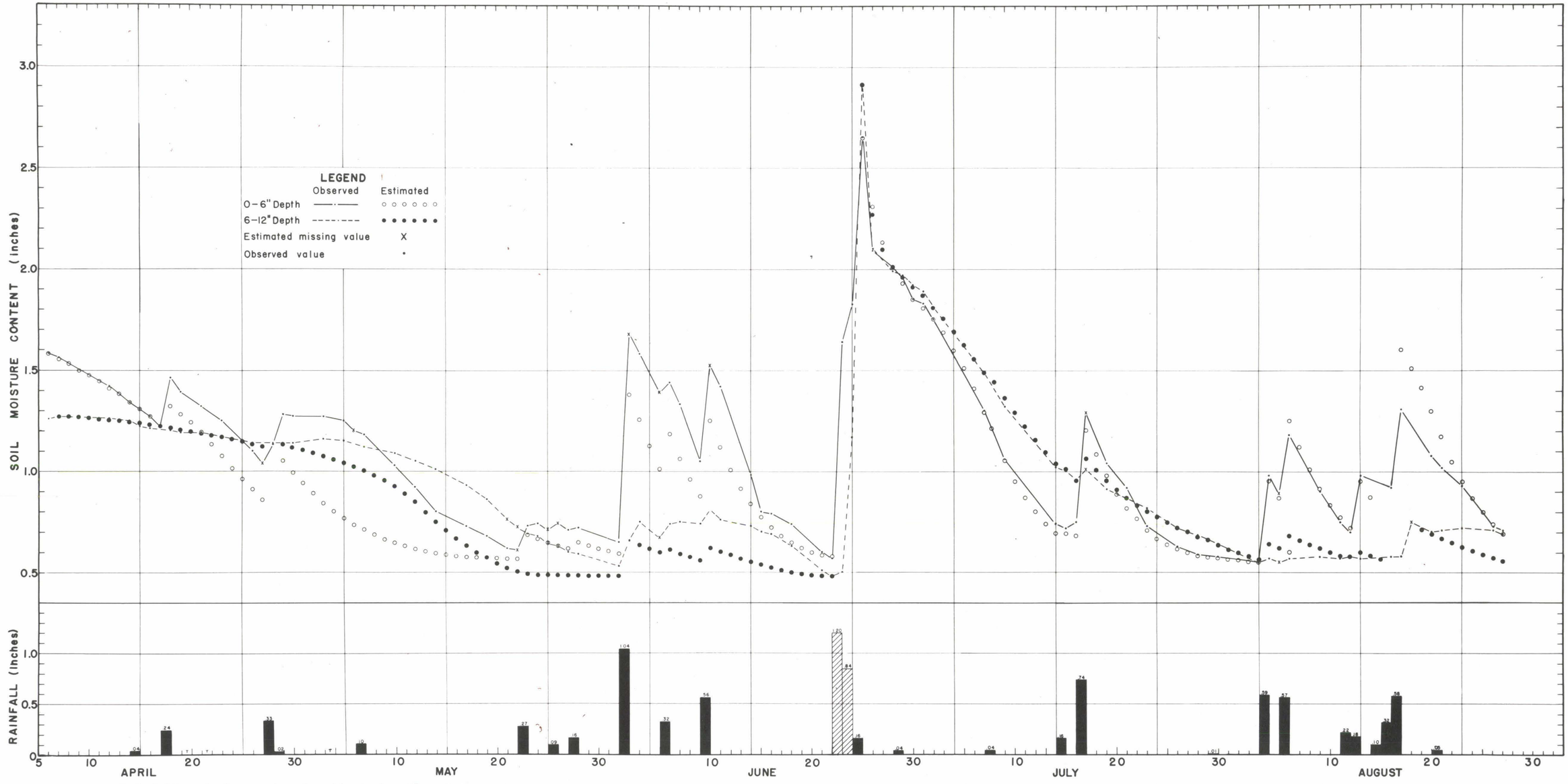

Figure 7.--Rainfall and observed and estimated soil moisture at Highway site.

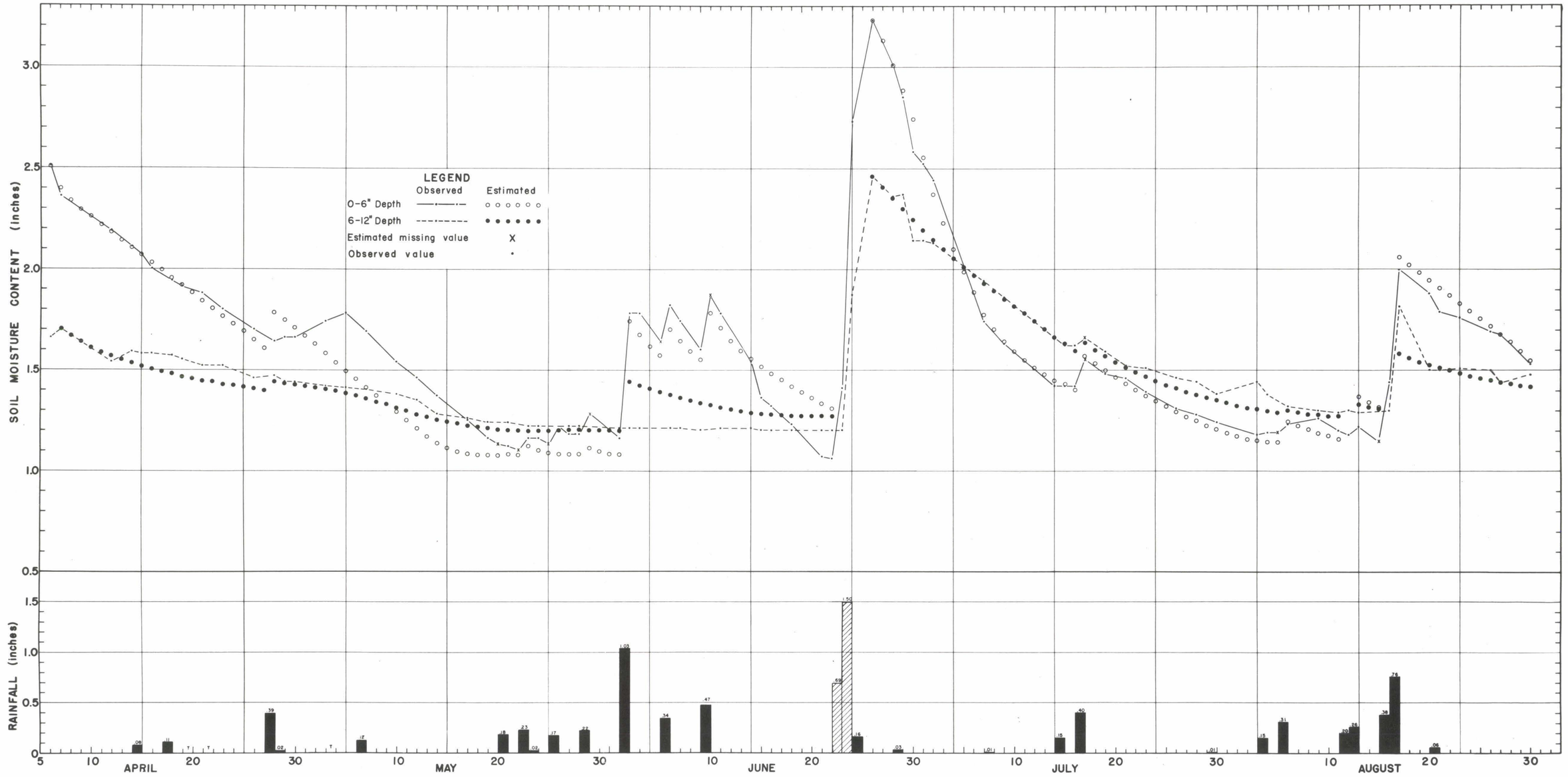

Figure 8.--Rainfall and observed and estimated soil moisture at Gumbo site.

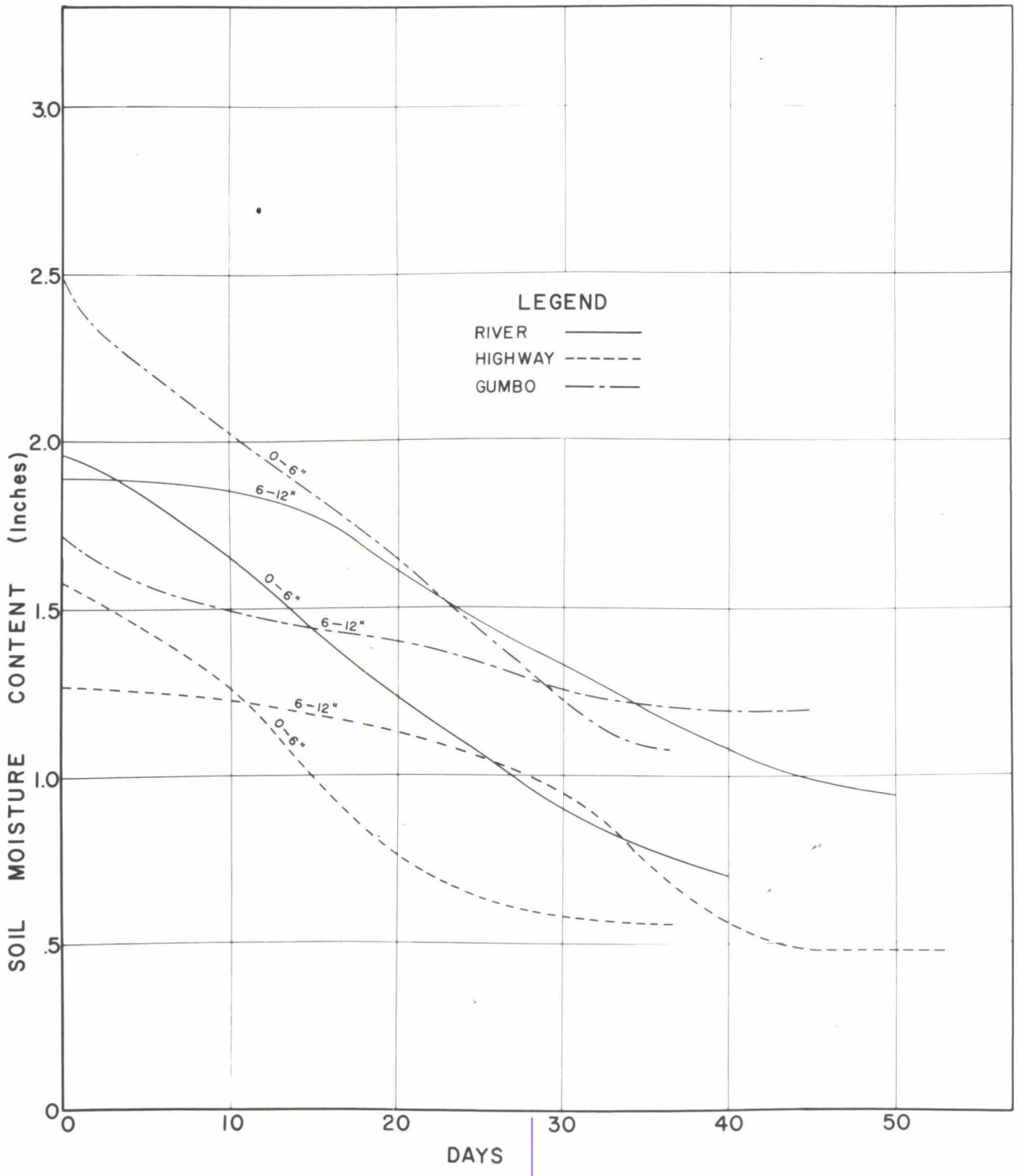

Figure 9.--Soil moisture depletion curves for the spring season.

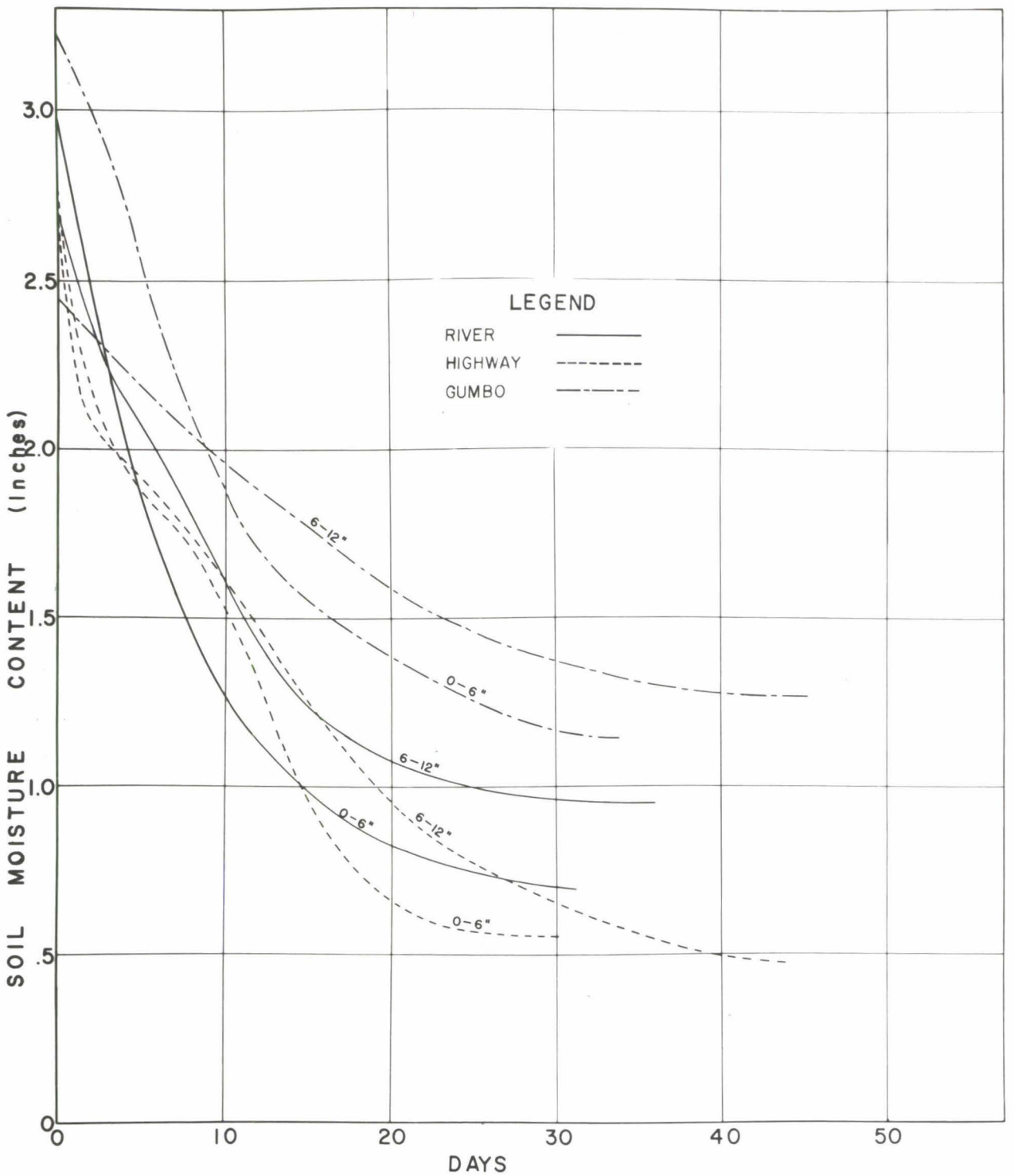

Figure 10.--Soil moisture depletion curves for the summer season.

Table 21.--Soil moisture depletion

Days	Spring depletion (April-May)						Summer depletion (June-August)					
	0-6 inch depth			6-12 inch depth			0-6 inch depth			6-12 inch depth		
	River	Highway	Gumbo	River	Highway	Gumbo	River	Highway	Gumbo	River	Highway	Gumbo
	Inches											
0	1.961	1.580	2.492	1.890	1.271	1.718	2.980	2.850	3.227	2.696	2.790	2.454
1	1.940	1.554	2.393	1.890	1.269	1.680	2.725	2.369	3.120	2.517	2.260	2.396
2	1.918	1.528	2.333	1.889	1.265	1.648	2.464	2.168	3.010	2.355	2.080	2.345
3	1.893	1.499	2.292	1.888	1.262	1.620	2.235	2.037	2.885	2.231	2.011	2.292
4	1.864	1.470	2.253	1.886	1.259	1.596	2.026	1.942	2.739	2.143	1.966	2.238
5	1.834	1.439	2.218	1.884	1.254	1.573	1.845	1.871	2.540	2.064	1.915	2.188
6	1.801	1.409	2.178	1.881	1.250	1.565	1.697	1.814	2.365	1.981	1.861	2.139
7	1.766	1.374	2.140	1.877	1.245	1.539	1.568	1.763	2.218	1.893	1.802	2.090
8	1.729	1.340	2.103	1.872	1.240	1.522	1.453	1.700	2.089	1.797	1.743	2.045
9	1.690	1.303	2.067	1.864	1.233	1.509	1.352	1.617	1.972	1.700	1.680	2.002
10	1.651	1.264	2.028	1.855	1.228	1.495	1.266	1.525	1.865	1.605	1.612	1.961
11	1.611	1.219	1.991	1.844	1.220	1.482	1.193	1.429	1.770	1.509	1.545	1.921
12	1.570	1.169	1.953	1.831	1.212	1.470	1.133	1.314	1.698	1.419	1.473	1.882
13	1.526	1.109	1.915	1.816	1.202	1.459	1.080	1.181	1.638	1.344	1.399	1.848
14	1.480	1.050	1.878	1.798	1.192	1.448	1.029	1.062	1.589	1.282	1.321	1.810
15	1.433	.992	1.839	1.778	1.182	1.439	.984	.958	1.548	1.233	1.251	1.774
16	1.389	.940	1.800	1.753	1.173	1.430	.942	.874	1.510	1.193	1.184	1.735
17	1.347	.889	1.762	1.722	1.164	1.422	.906	.803	1.476	1.157	1.121	1.697
18	1.306	.841	1.726	1.685	1.153	1.415	.875	.745	1.435	1.128	1.062	1.660
19	1.268	.801	1.686	1.647	1.143	1.409	.848	.699	1.414	1.101	1.004	1.623
20	1.232	.765	1.647	1.662	1.131	1.400	.826	.662	1.384	1.076	.955	1.591
21	1.196	.732	1.603	1.577	1.119	1.390	.806	.631	1.357	1.056	.909	1.560
22	1.163	.704	1.556	1.546	1.103	1.379	.789	.609	1.330	1.039	.868	1.531
23	1.131	.680	1.512	1.515	1.089	1.368	.773	.591	1.303	1.023	.831	1.508
24	1.098	.659	1.470	1.484	1.072	1.353	.759	.580	1.279	1.010	.802	1.483
25	1.066	.641	1.430	1.456	1.058	1.340	.746	.573	1.255	.999	.773	1.460
26	1.032	.628	1.389	1.428	1.039	1.324	.735	.569	1.232	.988	.748	1.439
27	.998	.612	1.349	1.403	1.021	1.317	.724	.565	1.212	.981	.723	1.421
28	.964	.601	1.308	1.377	1.000	1.290	.715	.562	1.193	.973	.700	1.403
29	.930	.593	1.266	1.352	.979	1.274	.707	.561	1.179	.968	.678	1.388
30	.902	.585	1.226	1.329	.951	1.260	.700	.561	1.164	.963	.656	1.373
31	.874	.579	1.184	1.304	.924	1.247			1.154	.960	.636	1.360
32	.850	.575	1.150	1.278	.890	1.237			1.148	.958	.617	1.346
33	.828	.571	1.124	1.252	.849	1.228			1.143	.956	.590	1.333
34	.808	.570	1.102	1.227	.798	1.220				.954	.580	1.322
35	.789	.569	1.089	1.201	.749	1.213				.952	.564	1.311
36	.771		1.080	1.176	.704	1.208				.951	.549	1.302
37	.754			1.153	.667	1.201					.534	1.292
38	.737			1.129	.629	1.199					.521	1.283
39	.722			1.105	.597	1.199					.509	1.279
40	.708			1.083	.567	1.199					.499	1.273
41				1.068	.540	1.198					.490	1.270
42				1.038	.518	1.198					.483	1.270
43				1.021	.499	1.198					.480	1.270
44				1.005	.489	1.198					.479	1.270
45				.992	.483	1.198						
46				.980	.482							
47				.969	.482							
48				.960	.481							
49				.952	.481							
50				.945	.481							

Spring depletion curves were applicable through May. Summer depletions were used for June, July, and August. The spring depletion curves are not necessarily transition curves applicable to a summer-to-winter or a winter-to-summer transition period. The curves were developed from available observed soil moisture contents. There is no evidence to indicate how closely they might approximate transition conditions.

The Gumbo site is unique in another way. The most rapid depletion rate of record occurred from June 11 until June 22 at which time artificial rainfall was applied. This segment of depletion record was so far out of line with other segments that it was not used in developing final curves. However, it comes closer to depicting natural depletion rates during the summer. The explanation lies in the vegetation. This site was occupied primarily by shortlived annual weeds which make their growth during and shortly after the rainy season and promptly die for lack of moisture. They were probably cureing by June 22 and responded poorly to additional soil moisture. Depletion rates under these conditions would be slower than on River and Highway which were vegetated largely by perennial grasses. These same vegetation considerations account for the use of a Spring-Fall curve at Gumbo to cover the Spring and late August periods rather than to use summer curves throughout August as was done at River and Highway.

SOIL MOISTURE PREDICTION

Predictions of soil moisture were made for each site (figures 6 to 8, inclusive) using an initial soil moisture content, the daily record of rainfall, and the soil moisture accretion and depletion relationships. The actual procedure used is described in the report of the Priest River, Idaho soil moisture studies.[6/] Lacking Class II accretion relationships it was assumed that the artificial applications of rainfall in late June filled the available storage capacity.

The accuracy of the accretion and depletion prediction relationship can best be determined by comparison of predicted with observed values. The only values available for testing the prediction methods are the values from which the methods were developed. Therefore, some agreement is expected. The comparison should nevertheless provide some indication of expected forecast errors.

An indication of the range of expected forecast errors is shown in table 22. The mean deviation of estimated from observed soil moisture content at the River site was 0.10 inches for the 0-6-inch layer and 0.08 for the 6-12-inch layer. Mean deviations at the Highway site were 0.13 and 0.09 inches and at the Gumbo site 0.08 and 0.05 inches for the 0-6- and 6-12-inch layers, respectively.

6/ Helmers, Austin E. The development of methods for predicting soil moisture content. Report on the Priest River, Idaho study, 135 pp. Spokane, Wn., Inland Empire Research Center, Typed ms., 1953.

Table 22.--Deviation of estimated from observed soil moisture content

Site	0-6-inch Depth					6-12-inch Depth				
	Number of days	Mean deviation	Percentage of estimates within range of: .00-.10 inch	.11-.20 inch	.20 inch	Number of days	Mean deviation	Percentage of estimates within range of: .00-.10 inch	.11-.20 inch	.20 inch
		Inches					Inches			
River	60	.10	52	35	13	62	.08	69	24	7
Highway	60	.13	61	14	24	55	.09	66	28	6
Gumbo	71	.08	72	18	10	69	.05	90	6	4

The most pronounced deviation of estimated from observed values occurred at all three sites as a result of an unusually cold period from about April 27 to May 15. The observed depletion rates during the period were much lower than is probably normal. Considerable deviation also occurred on the Gumbo site from June 14 to June 22. This results from excluding the segment of the depletion curve for this period from the family of curves which deliniated the final curve (See depletion). Estimated values agree reasonably well with the observed values for the remainder of the period of record.

SUMMARY

Field and analytical soil moisture prediction procedures developed by the Forest Service for the Waterways Experiment Station, U. S. Army Corps of Engineers at Vicksburg, Mississippi were studied during April to August, inclusive, 1954 on the U. S. Range Livestock Experiment Station area near Miles City in eastern Montana on three study sites on two soil series under native range vegetation. The "River" and "Highway" sites were on Havre silt loam under a cover of grasses and annual forbs of from 2/10 to 4/10 density. The "Gumbo" site, on Bowdoin clay, was sparsely vegetated with annual weeds.

Soil moisture accretion and depletion relationships at each site were developed from records of soil moisture and rainfall. Separate spring and summer depletion relationships were found, reflecting the effectiveness of the two seasons in terms of soil moisture losses. The temperature climate was nearly "normal" but rainfall was deficient, 86 percent of normal, during the April through July period and excessive, 222 percent of normal, during August.

Soil moisture accretion and depletion relationships were used to estimate soil moisture for the period of record. Satisfactory agreement was obtained between estimated and observed soil moisture except for instances of unusual observed conditions such as unusually cold weather from April 27 to May 15.

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